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ICF, Inc., Washington, DC

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HAZARDOUS WASTE TANKS RISK ANALYSIS

DRAFT REPORT

Prepared for:

The Office of Solid Waste
U.S. Environmental Protection Agency

Prepared by:

ICF Incorporated
Pope-Reid Associates, Inc.

June 1986

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The purpose of this analysis was to assess the human health risks associated with: (1) the population of hazardous waste tanks under the current regulatory approach; and (2) the population of hazardous waste tanks under the various regulatory strategies considered in this analysis included interim status and permitted hazardous waste tanks, 90-day accumulation tanks, and small quantity generator interim status, permitted or 180-day accumulation tanks. The regulatory alternatives examined in this analysis included no revisions, full secondary containment, partial secondary containment and ground water monitoring, leak testing and ground water monitoring, and corrosion protection. Analysis of these regulatory alternatives allows for direct comparisons between risks presented by hazardous waste tanks under alternative regulatory scenarios.

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PREFACE

This report presents the methodology used and results obtained from an analysis of the human health risks associated with different regulatory scenarios for tanks that treat, store, or accumulate hazardous waste. The Economic Analysis Branch within the Waste Management and Economics Division of the EPA Office of Solid Waste was responsible for this analysis. EPA retained Pope-Reid Associates, Inc., for the development of a model that predicts the timing of various events that lead to tank failure, and, given failure, the quantity of waste that leaks out to the environment. EPA retained ICF Incorporated to integrate the results of the tank failure model with environmental transport, exposure and risk models, and to conduct the analysis of the risk associated with the various regulatory scenarios using these models.

The results developed to date are useful in helping determine the appropriate regulatory strategy to pursue regarding the regulation of hazardous waste tanks. However, the results are preliminary and subject to change with refinements currently being considered to the various models involved in the analysis.

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EXECUTIVE SUMMARY

On June 26, 1985, EPA proposed revisions to the Resource Conservation and Recovery Act (RCRA) regulations for managing hazardous wastes that are stored or treated in tanks. These revisions address a number of issues for hazardous waste tanks brought forth in the Agency's January 12, 1981 preamble to the current regulations, including: (1) the development of permitting standards under Part 264 for underground tanks that cannot be entered for inspection; and (2) the requirement under the 1984 RCRA Amendments that new underground tanks be equipped with leak detection systems. In addition, EPA is proposing revisions that fulfill aspects of EPA's regulatory strategy for tanks that were left unaddressed in the January 12, 1981 preamble and for which public comment was requested when the existing regulations for tanks were promulgated.

Executive Order 12291 and the Regulatory Flexibility Act (P.L. 96-354) impose requirements that need to be addressed in promulgating revised regulations for tanks used for hazardous waste storage, treatment, or accumulation. To fulfill part of these requirements, EPA has developed a hazardous waste tank risk analysis model to quantitatively assess the risks associated with releases of contaminants from hazardous waste tanks. This report presents the first results of EPA's hazardous waste tank risk analysis, and also discusses the methodologies and assumptions used in the analysis.

PURPOSE

The purpose of this analysis was to assess the human health risks associated with: (1) the population of hazardous waste tanks under the current regulations; and (2) the population of hazardous waste tanks under the various alternative regulatory strategies being considered by EPA. The population of tanks considered in this analysis included four tank categories: RCRA-permitted storage tanks; treatment tanks (that are not exempt under EPA's wastewater treatment exemption); small quantity generator (SQG) tanks; and accumulation tanks (tanks that store waste for less than 90 days and are therefore not required to obtain a RCRA permit).

The analysis is focused on five regulatory scenarios, designed to represent the proposed regulatory alternatives for hazardous waste tanks.[1] These scenarios are as follows:

- no revised regulatory requirements (baseline);
- secondary containment;

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[1] In addition, we are considering alternatives to the proposed regulations. We plan to evaluate vadose monitoring for appropriate volatile waste streams, corrosion protection with leak testing, and corrosion protection with vadose zone monitoring.

- partial secondary containment and ground-water monitoring;
- corrosion protection for portions of steel tanks in contact with the soil; and
- leak testing and ground-water monitoring.

Analysis of these five regulatory scenarios allows for direct comparisons between risks presented by hazardous waste tanks as they are currently being managed and under technical requirements set forth in the proposed regulations. By analyzing each scenario separately, we are able to evaluate technical requirements that are being considered as part of alternative regulatory strategies (e.g., corrosion protection), while also considering requirements that are central to the proposed regulations (e.g., secondary containment). Also, further examination of tank regulatory alternatives could include the evaluation of combinations of technical requirements (e.g., partial containment and corrosion protection) and, by using the scenarios listed above, we have the flexibility to analyze the reduction in risks for these alternatives.

METHODOLOGY

The main objective of our analysis was to compare the risks associated with the various proposed regulatory scenarios with the risks associated with the existing situation. In order to analyze existing tanks, we first needed to compile information on the existing population of hazardous waste tanks (i.e., determine what type of tanks exist today, their age, and what type of hazardous wastes are stored or treated in these tanks). We then needed to project the type of releases that are occurring or will occur from this existing population of tanks. These projections on the behavior of tanks provide an indication of what the future health risks associated with current operating practices and tank technologies will be.

The regulatory scenarios are based on changes to current operating practices and technologies. Consequently, we had to project the type of releases that would occur from tanks regulated under different tank operating and design specifications. One major part of our methodology, therefore, focuses on estimating releases from existing tanks regulated under the current and alternative regulatory scenarios. Another major part of our methodology focuses on using the projection of releases to estimate human health risk. We then use these risk estimates to compare the regulatory scenarios.

Hazardous waste treatment and storage tanks may be constructed of a variety of materials (e.g., carbon steel, stainless steel, concrete, and fiberglass-reinforced plastic) and may be located completely above-ground (on cradles or ongrade), partially underground (in-ground), or completely underground. Also, they may be of various sizes and ages and store a variety of wastes. Additionally, they may be located over a wide variety of hydrogeologic conditions, and may vary considerably in their proximity to human populations.

All of these variables may have substantial impact on risk, and thus needed to be considered in our analysis. Moreover, tank design and operating practices will have an effect on the risks associated with different hazardous waste tanks. Thus, we also needed to take these additional factors into consideration. Therefore, the methodology developed for this analysis differed from traditional environmental risk assessment methodologies in that it was necessary to account not only for factors such as waste stream composition and hydrogeologic conditions, but also for factors that influence the timing and magnitude of failure events associated with hazardous waste tanks. Due to the variability in tank designs, operating conditions, and hydrogeologic and waste stream parameters, it was determined that a simplified approach based on one or several case histories of failed tanks was not adequate to assess the risk reductions for the different regulatory scenarios on a nationwide basis. Rather, we believed it was important to analyze the types of failures that would most commonly occur for hazardous waste tanks, and to evaluate the effectiveness of the proposed regulations and alternative regulatory strategies in (1) preventing these failures; or (2) detecting these failures before significant damage to public health or the environment has occurred.

Based on this premise, we developed a risk assessment methodology for hazardous waste tanks. The approach uses broad-based mathematical models to evaluate the range of environmental conditions, operating standards, and design scenarios considered necessary for the analysis, and is supported by data bases containing information on model tank technologies, waste streams, hazardous chemicals, and hydrogeologic environments. The models we used for this study are:

- The Hazardous Waste Tank Failure (HWTF) Model, a Monte Carlo simulation model that predicts the timing of failure events for hazardous waste tanks and estimates release volumes associated with these failure events;

- The Tank Risk Analysis Model (TRAM), an exposure/risk model that estimates human exposure to hazardous chemicals via contaminated drinking water and calculates non-carcinogenic and carcinogenic risk to the exposed individual. Contaminant transport and degradation in the unsaturated and saturated zones are estimated using modified versions of the McWhorter-Nelson Wetting Front and Prickett-Lonnquist Random Walk models, respectively.

These models reference data bases that we developed to characterize the existing tank population. We developed the following four data bases:

- Model Tank Technology Data Base: contains information on 22 model tank technologies that represent the types of existing RCRA-permitted storage tanks, treatment tanks, small quantity generator tanks, and accumulation tanks.

- Waste Stream Data Base: contains information on 32 waste streams that represent the range of waste streams handled in the model tank technologies.
- Chemical Data Base: contains information on 120 hazardous chemicals, of which 36 are representative of chemicals found in hazardous waste tanks.
- Hydrogeologic Data Base: contains information on nine hydrogeologic settings that represent the range of settings encountered at tank facilities.

The methodology was developed specifically to allow for comparisons to be made between regulatory scenarios. It was not designed necessarily to allow various comparisons to be made between different types of tanks. Such comparisons could be made if the model tank technologies and waste streams were revised specifically for this purpose. This report focuses primarily on comparisons between regulatory scenarios and the reader is cautioned against attempting to draw final conclusions based on any other comparisons that one might be tempted to make with data presented in the report.

RESULTS

Before presenting the results, it is important to note that the results are preliminary, and thus may be subject to significant revisions following further review and additional modeling work (e.g., inclusion of an algorithm to account for the development of cracks over time in concrete tanks). The Tank Risk Analysis Model, and particularly the Hazardous Waste Tank Failure Model, are large and relatively complex models that rely on major assumptions resulting from the lack of data, and it is clear that certain model results are driven by these assumptions. Some of the results seem anomalous and we are reviewing the assumptions on which these results are based to determine if revised assumptions should be made. Therefore, we believe that while the results presented here are useful for comparing regulatory scenarios, they are less useful for comparing different tank technologies within a scenario. We further believe our review of the results of this very complex model can be aided greatly by comments we expect to receive on these preliminary results.

The analysis found that risks were reduced significantly for all tanks, with a typical reduction of about 50 percent in non-zero risk estimates, between baseline and secondary containment scenarios. More importantly, high risk situations (relative risks greater than 10^{-3}) were reduced by 80 percent or more for most tank technologies between baseline and secondary containment scenarios. Thus, from our analysis, we conclude that secondary containment systems, equipped with leak detection systems, are a very effective method of reducing the risks associated with hazardous waste tanks. Secondary containment systems prevent most releases from escaping to the environment, in most cases allowing hazardous wastes to be released only as a result of very low-probability, catastrophic events.

Based on the results of the risk analysis, we have ranked the regulatory scenarios in descending order of risk reduction from the baseline as follows:

- Secondary containment for all tanks;
- Partial containment and ground-water monitoring for in-ground and ongrade tanks;
- Leak testing and ground-water monitoring for underground tanks; and
- Corrosion protection for steel portions of tank in contact with the soil.

It is important to note that direct comparisons cannot be made between all scenarios (for example, partial containment and leak testing scenarios apply to completely different tank types); however, the above ranking is an overall indication of the effectiveness of the different scenarios in reducing risks compared to baseline.

Based on the regulatory scenarios that we examined, our results indicate that EPA's proposed requirements for full secondary containment is an effective strategy for preventing environmental damage caused by leaking hazardous waste tanks. For in-ground and ongrade tanks, the partial containment with ground-water monitoring, is in most cases, significantly less effective than full secondary containment. For underground tanks, leak testing with ground-water monitoring does not appear to be nearly as effective as full secondary containment; however, these results must be viewed with caution due to assumptions in our model that are currently being reconsidered and which may be significantly affecting our results. Finally, corrosion protection, without some form of leak detection, does not appear to be very effective in reducing the risks presented by carbon steel and stainless steel tanks. Once again, however, we attribute considerable uncertainty to these results due to model assumptions and limitations.

The risk estimates developed in this analysis are not only a function of tank failure events and release volumes, but are also controlled by the waste streams stored in a particular tank and the hydrogeologic settings in which the tanks are located. In considering regulatory alternatives for tanks, such as a risk-based variance to secondary containment requirements, it would be very important to consider these variables on a site-specific basis.

Our analysis was not designed to compare these factors, but rather was constructed to obtain comparative risk results for different regulatory scenarios. However, by comparing the generic flow fields and waste streams included in our analysis, some insight may be gained into what hydrogeologic and waste parameters most greatly influence risk. Our findings can be summarized as follows:

- Hydrogeologic setting affects risk such that, for a given technology and waste stream, risk is generally greater for flow fields with slower ground-water velocity. This conclusion is somewhat counter-intuitive, and is dependent on complex interactions between contaminant mobility and persistence, ground-water dilution and dispersion, and the presence of non-aquifer layers. However, it can be said that, for most waste streams, flow fields with higher velocities present the lowest risk. In developing risk-based standards, the ground-water scenario must be considered in conjunction with information on potentially exposed populations and waste stream characteristics.

- Many waste streams found in hazardous waste tanks present relatively high risks, due to their highly concentrated nature. Among the highest-risk wastes are spent solvents, certain heavy metal wastes (particularly those containing thallium and arsenic), phenol, and reactive wastes (acrylonitrile/cyanide, 2,4-dinitrotoluene, etc.). More dilute wastes such as spent pickle liquor and petroleum refining wastes generally present lower risks.

CHAPTER 1

OVERVIEW OF HAZARDOUS WASTE TANK RISK ANALYSIS

1.1 INTRODUCTION

Tanks that are used to store or treat hazardous waste are currently regulated under the Resource Conservation and Recovery Act (RCRA) [40 CFR Part 264 requirements (January 12, 1981)]. These regulations address minimum design standards and operating practices. However, evidence suggests that these tanks, even as currently regulated, may present a potential threat to public health and the environment. Also, the Hazardous and Solid Waste Amendments of 1984 (RCRA Amendments) require that more stringent regulations be promulgated with regard to underground hazardous waste tanks that cannot be entered for inspection.

In the June 26, 1985, Federal Register, EPA proposed a more stringent and comprehensive strategy for hazardous waste tanks that addresses both design and operating standards, by: (1) replacing minimum shell thickness and design requirements with regulations requiring full secondary containment, or ground-water monitoring with partial containment, or leak testing with ground-water monitoring for underground tanks; (2) requiring installation supervision and corrosion evaluation by certified experts; and (3) requiring periodic inspections for above-ground and in-ground tanks.

The purpose of this analysis was to assess the human health risks associated with: (1) the population of hazardous waste tanks under the current regulations; and (2) the population of hazardous waste tanks under the various alternative regulatory strategies proposed by EPA. The population of tanks considered in this analysis included four tank categories; RCRA-permitted storage tanks; treatment tanks that are not exempt under EPA's wastewater treatment exemption; small quantity generator (SQG) tanks; and accumulation tanks (tanks that store waste for less than 90 days and are therefore not required to obtain a RCRA permit).

In this chapter, we present an overview of our analysis. In Section 1.2, we outline the proposed regulations for these hazardous waste tanks and discuss alternative strategies that EPA is considering for these tanks. Section 1.3 then briefly presents the methodology we used to assess and compare human health risk associated with the various regulatory scenarios. The final section describes the organization of the remainder of this report.

1.2 PROPOSED REGULATIONS AND REGULATORY ALTERNATIVES FOR HAZARDOUS WASTE TANKS

EPA has recently proposed regulations for tanks that are used to store or treat hazardous wastes (Federal Register, June 26, 1985). These regulations would supplement and, in some instances, replace current hazardous waste tank regulations that were promulgated on January 12, 1981. These new regulations would complete the Agency's regulatory strategy for managing hazardous waste tanks, and address requirements of the 1984 RCRA Amendments with respect to underground tanks. The more stringent controls in the proposed regulations should substantially improve tank owners' or operators' ability to contain releases from tank systems and, therefore, should provide needed protection of human health and the environment. Moreover, EPA has concluded that the proposed measures, while substantially reducing risks associated with hazardous waste tanks, are cost-effective when compared to alternative protection strategies such as shell thickness requirements.

The proposed regulations for tanks that are used to store or treat hazardous waste are being considered to supplement current requirements defined in 40 CFR Parts 260, 262, 264, 265, and 270 (SWH-FRL 2791-1); Hazardous Waste Management Systems; Standards for Hazardous Waste Storage and Treatment Tank Systems. The proposed regulations address both design and operating standards and can be summarized as follows:

- The installation of all new tanks would be required to be supervised and observed by a certified expert (registered professional engineer or equivalent) who would prepare a written statement attesting to the proper installation of the tank. Also, the installation site would be required to be inspected by a corrosion expert, who would also be required to supervise the installation of a corrosion protection system (e.g., an impressed current system) if such a system was considered necessary or was required for a particular tank.

- All new tank systems would be required to be enclosed in a full secondary containment system that would encompass not only the body of the tank but all ancillary equipment (pipes, pumps, valves, etc.). This secondary containment system would be required to be equipped with a leak detection system for detection of leaks within 24 hours of release.

- Facilities with existing tank systems would be required to conduct integrity assessments of the hazardous waste tank systems. Tanks that are found to be leaking or unfit for further use must be repaired or replaced with full secondary containment.

- Facilities with non-leaking tank systems would be exempt from the full secondary containment requirement if they: (1) installed monitoring wells and implemented a ground-water monitoring program; and (2) constructed partial containment for all above-ground portions of their tank systems. Because partial containment is not applicable to underground tanks, these tanks would have the option of semi-annual leak testing and ground-water monitoring rather than full secondary containment.

- Inspection requirements would be upgraded to include inspection of cathodic protection systems and of entire tank systems for leaks, cracks, corrosion, and erosion that may lead to releases.

The containment approach outlined in the proposed regulations is presented in Exhibit 1-1.

These regulations have been proposed partly in response to the 1984 RCRA Amendments and partly as a result of limitations in the existing regulations. One limitation relates to the fact that some hazardous waste tanks, as they are currently being managed, do leak and, therefore, may present a substantial threat to human health and the environment. Another limitation is that certain existing tank standards are impractical to implement or may only be effectively applied at some facilities. An example is the minimum shell thickness requirement for hazardous waste tanks, which has proven to be applicable only for above-ground steel tanks, as many or most of the testing mechanisms for shell thickness do not work adequately for other tank types (e.g., concrete and underground tanks). It is the intent of the proposed regulations to address these limitations.

As outlined in the introduction, the purpose of this analysis was to examine the relative effectiveness of the proposed alternative regulatory requirements. For this purpose we developed five regulatory scenarios, designed to represent the range of possible management alternatives for hazardous waste tanks. These scenarios are as follows:

- no revised regulatory requirements (baseline);
- secondary containment;
- partial secondary containment and ground-water monitoring for ongrade and in-ground tanks;
- corrosion protection for portions of steel tanks in contact with the soil; and
- leak testing and ground-water monitoring for underground tanks.

Analysis of these five regulatory scenarios allows for direct comparisons between risks presented by hazardous waste tanks as they are currently being managed and under technical requirements set forth in the proposed regulations. By analyzing each scenario separately, we are able to evaluate technical requirements that are being considered as part of alternative regulatory strategies (e.g., corrosion protection), while also considering requirements that are central to the proposed regulations (e.g., secondary containment). Also, further examination of tank regulatory alternatives could include the evaluation of combinations of technical requirements (e.g., partial containment and corrosion protection) and, by using the scenarios

EXHIBIT 1-1

PROPOSED REGULATIONS FOR HAZARDOUS WASTE TANKS

Tank Category	New/Existing	Location	Containment Requirements
RCRA-Permitted Storage Tanks, Treatment Tanks a/	New	above-ground in-ground	Full Secondary Containment
		underground	Full Secondary Containment
	Existing b/	above-ground in-ground	Full Secondary Containment, or Partial Containment with Ground-Water Monitoring
		underground	Full Secondary Containment, or Semi-Annual Leak Testing with Ground-Water Monitoring
Accumulation Tanks, c/ SQG Tanks d/	New	above-ground, in-ground, underground	Full Secondary Containment
	Existing b/	above-ground, in-ground, underground	Full Secondary Containment

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a/ Regulations do not apply to treatment tanks exempt under Part 264 wastewater treatment exemption.

b/ Existing tanks must comply within one year of effective date of final regulations.

c/ Accumulation tanks are not currently covered under RCRA Part A & B permits and may not store wastes for more than 90 days.

d/ Although SQG tanks can be either storage or accumulation tanks, we have assumed that all SQG tanks will be operated as accumulation tanks to avoid the need to obtain a RCRA storage permit.

listed above, we have the flexibility to analyze the reduction in risks for these alternatives.[1]

1.2.1 Baseline Scenario

In the baseline scenario, we assume that all tanks are managed and operated in compliance with the existing regulations. These regulations basically involve good operating practices, such as regular visual inspections and waste compatibility with the tank material. Under this scenario there are no technical requirements that prevent releases from the primary containment, nor are there requirements that would assist in the early detection of releases from underground or in-ground hazardous waste tanks. Under the baseline scenario, releases from hazardous waste tanks are only detected if: (1) the leak is above-ground and large enough to be visually detected or (2) the leak is so large that at the time the contents are normally removed it is obvious that the tank is not as full as it should be.

1.2.2 Secondary Containment Scenario

Under the secondary containment scenario, we assume that all hazardous waste tank systems are replaced by new tank systems equipped with full secondary containment that prevent leaks from the tank and all ancillary equipment from escaping to the surrounding environment. As prescribed by the proposed regulations, secondary containment systems in our model scenario are further fortified by leak monitoring that allows for the rapid detection of leaks (by remote or visual inspection) that have accumulated within the secondary containment system. As a result, the full secondary containment scenario usually prevents releases to the environment from primary tank failures.

Although full secondary containment is probably the most effective approach to tank management for minimizing releases to the environment, it is not 100 percent effective. Tanks with full secondary containment may release to the environment if there is a catastrophic failure such as an earthquake or explosion or if there is a failure of the secondary containment system. Thus, there may still be some risk associated with tanks that have full secondary containment systems.

Full secondary containment technologies vary depending upon the tank type. In this analysis, we assume that above-ground, on cradle tanks are fitted with a lined concrete pad surrounded by diking to prevent leaks from escaping. We assume that on-grade tanks are replaced with tanks of the same size and material of construction on top of lined concrete pads surrounded by diking. Full secondary containment for underground and in-ground tanks is achieved by replacing existing tanks with double-walled tanks of the same size and tank material. Finally, we assume that above-ground piping and ancillary equipment for all tanks is contained by concrete trenches, while underground piping systems meet secondary containment requirements through the installation of double-walled pipes.

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[1] In addition to the alternative proposed requirements, we plan to evaluate vadose zone monitoring for appropriate volatile waste streams, corrosion protection with leak testing, and corrosion protection with vadose zone monitoring.

1.2.3 Partial Secondary Containment and Ground-Water Monitoring Scenario

In the partial containment and ground-water monitoring scenario of our analysis, all above-ground portions of a tank system are equipped with secondary containment, and saturated zone monitoring wells are installed downgradient to detect releases from portions of the tank not enclosed in the containment system. In this scenario, we assume that partial secondary containment is achieved by a lined concrete pad and diking surrounding, but not underneath, ongrade or in-ground tanks. Above-ground piping is provided with concrete trenches to complete the partial containment. Partial secondary containment does not provide protection for the portion of the tank system that is ongrade or in the ground.

Because releases from portions of tanks not contained within the partial containment system will be released directly to the environment and may therefore present risk to human health, the proposed regulations also require ground-water monitoring for these systems in order to detect releases before contamination of a drinking water well occurs. In this scenario, we consider ground-water monitoring to be represented by saturated zone wells that are located 10 meters downgradient from the tank. We assume that detection occurs in the year a monitoring well concentration for any of the contaminants in the tank waste stream exceed a detectable threshold. Once detection has occurred, we assume that the tank is taken out of operation, thereby removing the source of further contamination. We then continue to model the transport of wastes released before tank removal (i.e., no ground-water pumping and treatment is assumed). Therefore, some released contaminants will not be contained and will migrate to exposure wells.

1.2.4 Corrosion Protection Scenario

Studies of metal tank systems indicate that the major cause of failure for systems in contact with the soil is external corrosion. Because the majority of tanks used to store or treat hazardous waste are made of carbon steel and are in contact with the soil, it can be seen that corrosion represents a very significant risk to the integrity of many hazardous waste tanks.

While the installation of full secondary containment effectively isolates the main tank system from the soil and prevents corrosion, tanks that are retrofitted with partial containment will still have some portion of their systems in direct contact with the soil and thus may still be subject to corrosion. Moreover, installation of full secondary containment or partial containment and ground-water monitoring is relatively expensive, and, in the case of the latter, clean-up costs may be substantial for releases that occur before detection. Therefore, we have developed a scenario in which cathodic protection for all metal tank systems in contact with the soil is utilized as the only protective measure to prevent tank releases. This scenario will allow us to evaluate not only the reduction in risk between the baseline and corrosion protection scenarios, but will also give some indication as to whether corrosion protection may be a valuable addition to other protective measures.

In the corrosion protection scenario, all metal tank systems that have some portion of the tank or ancillary equipment in contact with the soil are assumed to be fitted with cathodic protection. Thus, the probability of failures due to corrosion is reduced, while the probability of all other events remains the same. This allows us to directly assess the reduction in risk attributable to installing corrosion protection. However, we have not yet examined the reduction in risk attributable to corrosion protection combined with other protective measures (e.g., leak testing).

1.2.5 Leak Testing and Ground-Water Monitoring Scenario

The final regulatory scenario considered by our analysis is leak testing (i.e., integrity assessment) and ground-water monitoring. In this scenario, we assume that semi-annual leak tests are performed on underground hazardous waste storage tank systems and that these tank systems are also equipped with saturated zone monitoring wells.

Leak testing is only applicable for underground tanks because such tests require stable temperatures to be reliable. The purpose of periodic leak testing is to detect a leak in an underground tank before extensive environmental damage or adverse human health effects occur. Currently, there are no proven leak tests available for tanks containing hazardous waste. Therefore, for this analysis, we assume that an underground hazardous waste tank is emptied, cleaned, and filled with water and a hydrostatic leak test is used.

It is important to note that leak tests are only reliable for leaks greater than some minimum size; thus, the test will fail to detect very small leaks. In addition, there is also some probability that the leak test will fail even if the leak is large enough to be detectable. For this analysis, we assume that the leak test is 100 percent reliable if the leak is large enough to be detectable. The more frequently a leak test is required, the more likely it is that a leak will be detected before excessive environmental damage or adverse human health effects occur. This analysis assumes a semi-annual leak testing frequency as proposed in the June 26, 1985, Federal Register.

In the next section, we present a brief description of the methodology used to assess the risks associated with each of the five regulatory scenarios considered in the analysis.

1.3 OVERVIEW OF RISK ASSESSMENT METHODOLOGY

Hazardous waste treatment and storage tanks may be constructed of a variety of materials (e.g., carbon steel, stainless steel, concrete, and fiberglass-reinforced plastic (FRP)) and may be located completely above-ground (on cradles or ongrade), partially underground (in-ground), or completely underground. Also, they may be of various sizes and ages, and store a variety of wastes. Additionally, they may be located over a wide variety of hydrogeologic conditions, and may vary considerably in their proximity to human populations.

All of these variables may have substantial impact on risk, and thus needed to be considered in our analysis. Moreover, tank design and operating practices will have an effect on the risks associated with different hazardous waste tanks; thus, these factors also needed to be taken into consideration. Therefore, the methodology developed for this analysis differed from traditional environmental risk assessment methodologies in that it was necessary to account not only for factors such as waste stream composition and hydrogeologic conditions, but also for the range of various failure events associated with hazardous waste tanks, and for time-dependent processes such as corrosion. We analyzed the types of failures that would most commonly occur for hazardous waste tanks, and evaluated the effectiveness of the proposed regulations and alternative regulatory strategies in terms of (1) preventing these failures; or (2) detecting these failures before significant damage to public health or the environment has occurred.

The main objective of our analysis was to compare the risks associated with the various proposed regulatory requirements to the risks associated with the existing tank population. In order to analyze the existing tank population in more detail we divided the tank population into categories of tanks: RCRA-permitted storage tanks, small quantity generator tanks, accumulation tanks (less than 90 day storage), small quantity generator tanks and treatment tanks. For each tank category we then identified types of tank technologies that are associated with each tank category. For example, we identified two tank technologies to represent small quantity generator tanks: (1) underground, carbon steel tanks; and (2) above-ground, carbon steel tanks. In addition, because the types of waste streams contained in a tank influence the risk associated with the tank, we identified the most common types of waste streams handled by each type of tank technology. Furthermore, because the hydrogeologic setting surrounding a tank influences contaminant transport to points of exposure, we identified several generic hydrogeologic settings to be representative of the settings surrounding tanks.

The four main parts of our risk assessment methodology are summarized below:

- Identify characteristics of the existing hazardous waste tank population;

- Project the type of releases that would occur from tanks regulated under different operating and design specifications (i.e., the regulatory alternatives we examined for this study);

- Estimate the human health risk associated with each tank technology and regulatory scenario; and
- Summarize the range of risk estimates for each tank technology and regulatory scenario.

Step 1: Identify Tank Population Characteristics

To identify important characteristics for the existing hazardous waste tank population, we compiled four data bases using available information. Information on tank technologies; hazardous waste streams most commonly handled in tanks; physical, chemical, and toxicological properties of toxic chemicals in these wastes; and hydrogeologic settings surrounding tanks was compiled into four data bases. These data bases consist of 22 model tank technologies, 9 generic hydrogeologic settings, 32 waste streams and 36 toxic chemicals that represent the range of characteristics associated with hazardous waste tanks.

Step 2: Project Releases

After we characterized the existing tank population, we needed to project the types of releases that are occurring or will occur from this existing population of tanks. These projections on the behavior of tanks provide an indication of what the future health risks associated with current operating practices and tank technologies will be. Because the regulatory scenarios we are analyzing are based on changes to current operating practices and technologies, we had to project the types of releases that would occur from tanks regulated under different operating and design specifications. Consequently, the second part of our methodology focuses on estimating releases form existing tanks regulated under the current and alternative regulatory scenarios.

In order to project release volumes for these tanks, we developed the Hazardous Waste Tank Failure (HWTF) Model, a Monte Carlo simulation model to predict failure events for hazardous waste tanks and to estimate release volumes associated with these failure events. We used the HWTF model to predict failure events and release volumes over the 20-year time horizon for each of the 22 model tank technologies considered in the analysis. In total, 250 "release profiles", or sets of year-by-year releases, are produced for each modeled tank technology under a particular regulatory scenario. A statistical technique known as cluster analysis is then used to select five or six representative release profiles from the 250.[2] These representative profiles are weighted and used as inputs the risk model developed in the next step.

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[2] Ideally, we would use all 250 release profiles to obtain 250 risk estimates for each tank. However, using 250 release profiles to generate risk estimates for each model tank, regulatory scenario, ground-water setting and waste stream, would be a computationally intensive task. Therefore, we used cluster analysis techniques to select the most representative profiles. as inputs to the Tank Risk Analysis Model.

Step 3: Estimate Human Health Risk

The third part of our methodology focuses on using the projection of releases to estimate human health risk. We predicted the transport of contaminants released from tanks to human exposure points (i.e., drinking water wells). We then generated human health risk estimates associated with individuals consuming this contaminated drinking water. We used these risk estimates to compare the regulatory scenarios.

We developed the Tank Risk Analysis Model (TRAM), an exposure/risk model, to estimate human exposure to hazardous chemicals via contaminated drinking water and to calculate non-carcinogenic and carcinogenic risk to the exposed individual.

The Tank Risk Analysis Model is a non-steady-state (i.e., time-varying) model that consists of three major components: an unsaturated zone transport model, a saturated zone transport model, and an exposure/risk model.[3] Contaminant transport and degradation in the unsaturated and saturated zones are estimated using modified versions of The McWhorter-Nelson Wetting Front and Prickett-Lonnquist Random Walk models, respectively. The major components of TRAM are illustrated in Exhibit 1-2.

Step 4: Summarize Risk Estimates

The technique used to compare regulatory scenarios constitutes the final part of our methodology. In general, for each tank technology and regulatory scenario we estimated 324 risk estimates.[4] These 324 risk estimates represent the range of risk estimates associated with a tank technology.[5]

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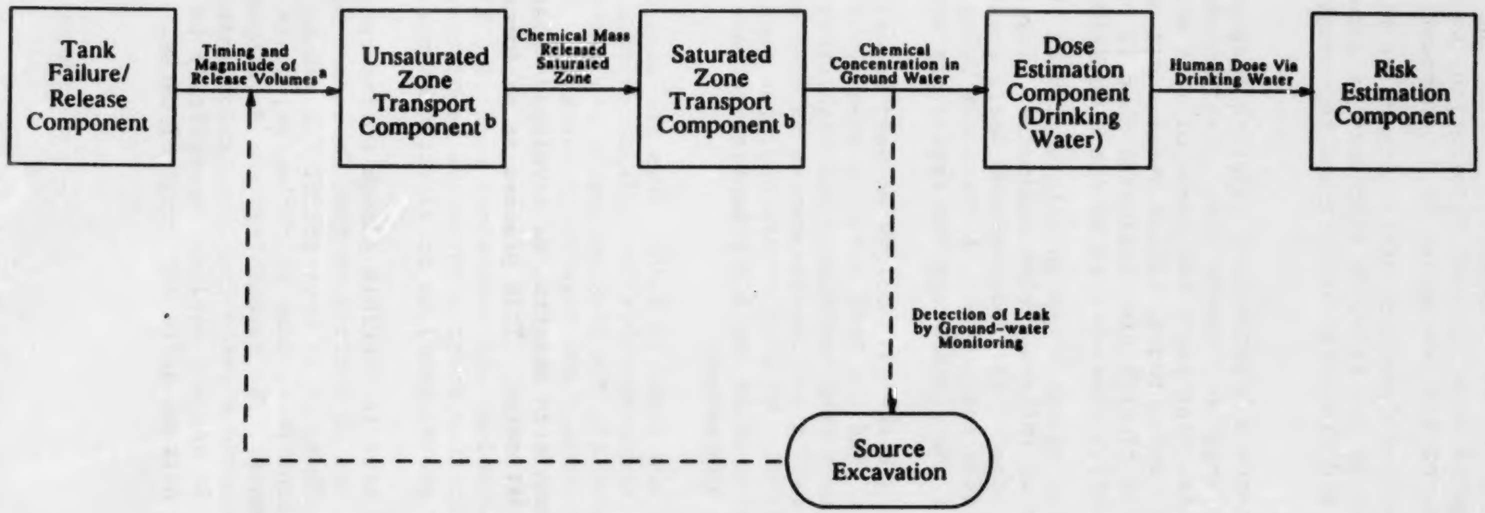
[3] In order to maintain consistency with other similar analyses (e.g., Liner Location Risk and Cost Analysis Model studies), we chose 400 years as the potential exposure period in our analysis. The 400-year time horizon is long enough to capture most of the risk associated with releases of contaminants (i.e., a long enough time horizon such that most contaminants reach the exposure point within this time frame) and short enough to be computationally feasible.

[4] There are approximately six waste streams per technology, nine hydrogeologic settings per technology and six sets of annual release volumes per technology. These factors are described in more detail in the following chapters of this report.

[5] Due to the variability in tank designs, operating conditions, and hydrogeologic and waste stream parameters, it was considered that a simplified approach based on one or several case histories of failed tanks was not adequate to assess the risk reductions for the different regulatory scenarios on a nationwide basis. Consequently, we estimated a range of risk estimates for each tank technology and regulatory scenario.

EXHIBIT 1-2

FLOWCHART OF THE TANK RISK ANALYSIS MODEL


Tank Failure/ Release Component
Timing and Magnitude of Release Volumes[a]
Unsaturated Zone Transport Component[b]
Chemical Mass Released Saturated Zone
Saturated Zone Transport Component[b]
Chemical Concentration in Ground Water
Dose Estimation Component (Drinking Water)
Human Dose Via Drinking Water
Risk Estimation Component
Detection of Leak by Ground-water Monitoring
Source Excavation

[a] Six representative release profiles, selected using cluster analysis techniques, are input to TRAM.

[b] Chemical mass can also be degraded or removed from the modeling system in these components.

There are several ways to summarize these 324 risk estimates. For example, we could summarize this range using the minimun, mean, median, or maximum risk estimate associated with the 324 estimates. Because the choice of such a summary measure aggregates much relevant information, we chose to derive frequency distributions of risk estimates (e.g., percent of risk estimates that are 10^{-5}). We derived frequency distributions of risk estimates by weighting each estimate by its relative frequency of occurrence in terms of waste stream handled, hydrogeologic setting and representativeness of annual releases.

Exhibit 1-3 represents a hypothetical relative frequency distribution of risk estimates for above-ground, carbon steel, small quantity generator tanks. This distribution represents the range of risk estimates associated with the population of above-ground, carbon steel small quantity generator tanks. For example, the distribution indicates that 10 percent of all above-ground small quantity generator tanks are associated with risk estimates of 10^{-6}. This distribution was based on information on the relative frequency of factors that influence risk estimates. For example, we determined that 28 percent of all above-ground small quantity generator tanks store strong acids or alkaline wastes. A frequency distribution was derived for each combination of tank technology and regulatory scenario.

Exhibit 1-4 summarizes the methodology we used to derive each frequency distribution. We first used the HWTF Model to simulate 250 potential release profiles associated with a tank technology and regulatory alternative. We did a cluster analysis to select six representative release profiles from the 250 potential release profiles. We also determined, for each representative release profile, the percent of the 250 potential release profiles that the representative profile represents.

These six profiles are input to TRAM. Then for each waste stream, hydrogeologic setting, and representative release profile, TRAM generates a risk estimate. Approximately 324 risk estimates are generated for each combination of tank technology and regulatory scenario. Using these risk estimates and their associated weights, we developed relative frequency distributions of risk estimates. This process is performed for each combination of tank technology and regulatory scenario, allowing the risk estimates for a specific tank under alternative regulatory scenarios (e.g., baseline and secondary containment) to be directly compared.

The methodology we used is flexible enough to incorporate a wide variety of generic situations, but is limited in that it cannot be applied to specific real-site situations. Thus, it is most useful for making broad comparisons between regulatory alternatives, tank technologies, waste streams, and hydrogeologic environments. The methodology was developed specifically to examine the existing hazardous waste tank population under alternative regulatory scenarios. It was not designed necessarily to allow various comparisons to be made between different types of tanks.

EXHIBIT 1-3

HYPOTHETICAL RELATIVE FREQUENCY DISTRIBUTION OF RISK ESTIMATES FOR A TANK TECHNOLOGY AND REGULATORY SCENARIO

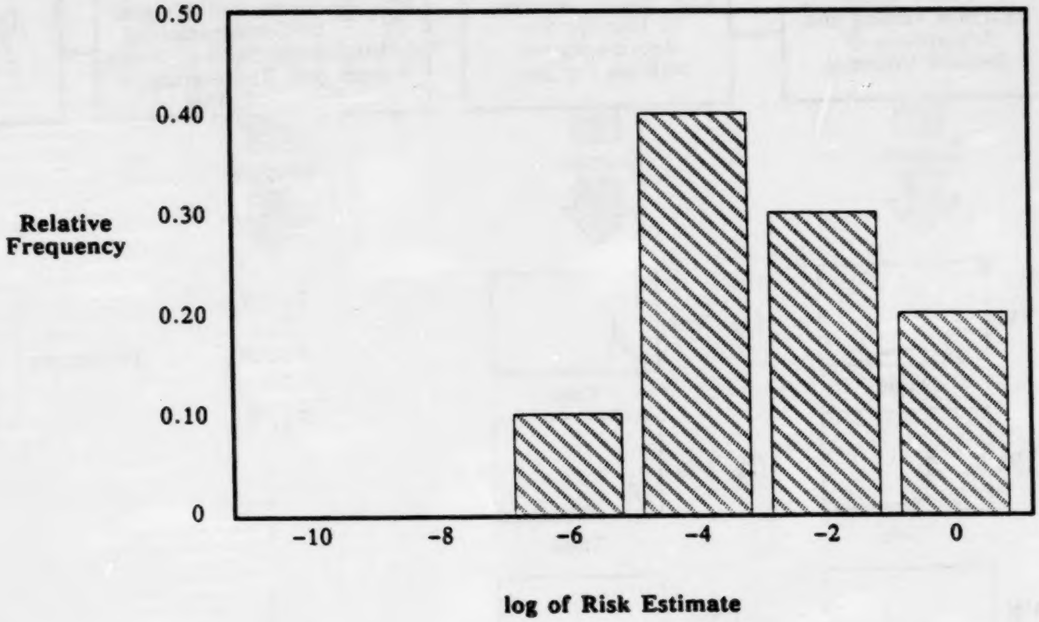
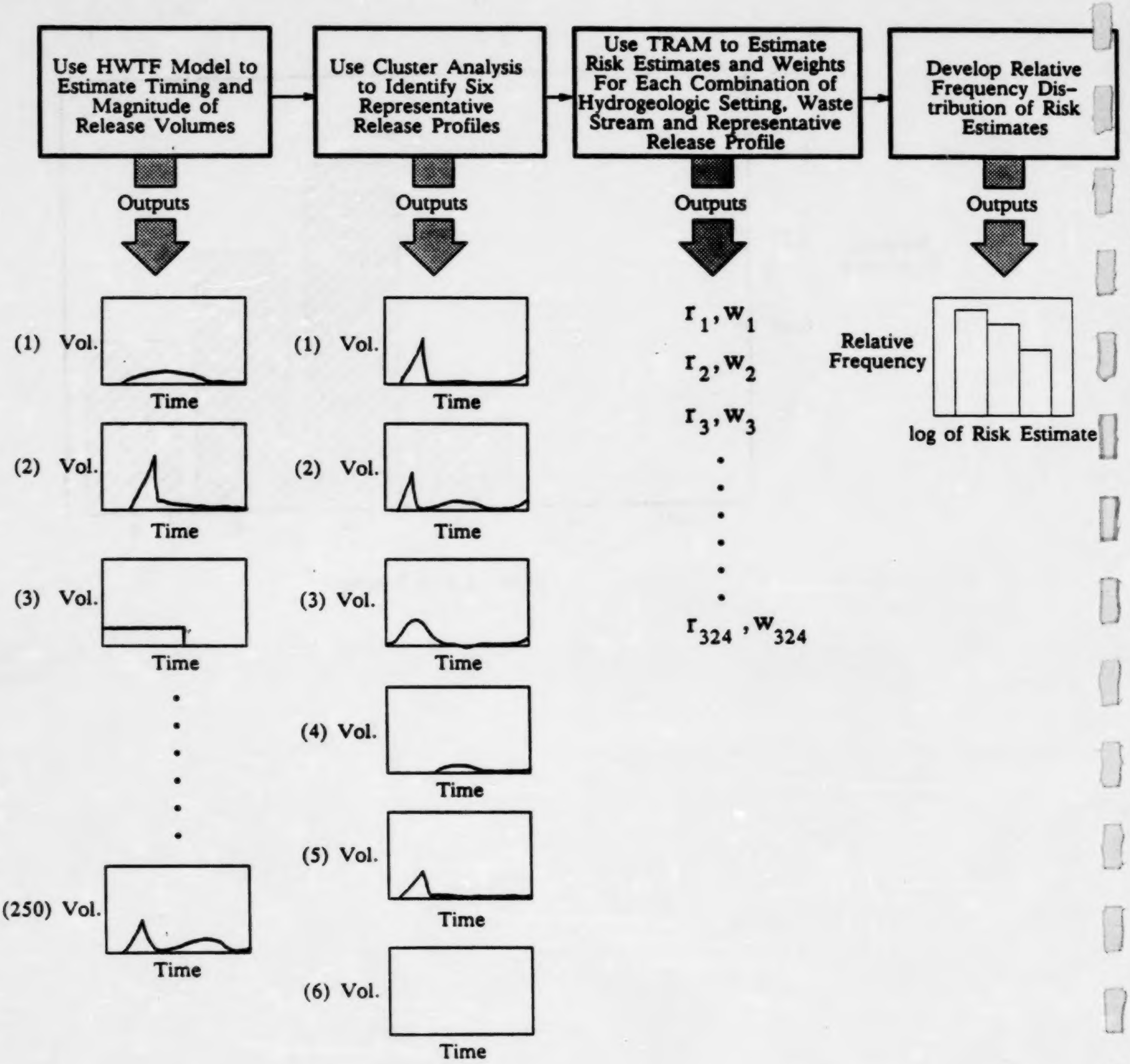


EXHIBIT 1-4

METHODOLOGY TO ESTIMATE FREQUENCY DISTRIBUTION OF RISK ESTIMATES FOR EACH TANK TECHNOLOGY AND REGULATORY SCENARIO


Use HWTF Model to Estimate Timing and Magnitude of Release Volumes
Use Cluster Analysis to Identify Six Representative Release Profiles
Use TRAM to Estimate Risk Estimates and Weights For Each Combination of Hydrogeologic Setting, Waste Stream and Representative Release Profile
Develop Relative Frequency Distribution of Risk Estimates
Outputs
Outputs
Outputs
Outputs
(1) Vol.
Time
(2) Vol.
Time
(3) Vol.
Time
(250) Vol.
Time
(1) Vol.
Time
(2) Vol.
Time
(3) Vol.
Time
(4) Vol.
Time
(5) Vol.
Time
(6) Vol.
Time
r_1, w_1
r_2, w_2
r_3, w_3
r_{324}, w_{324}
Relative Frequency
log of Risk Estimate

The main reason that tank technologies cannot be readily compared is that they differ in several factors, such as size, age, waste streams handled, and material of construction. Such comparisons can be made if the model tank technologies and waste streams were revised specifically for this purpose (i.e., more of the tank technologies were modeled to have the same size, age, or waste streams handled). This report focuses primarily on comparisons between regulatory scenarios, and the reader is cautioned against attempting to draw final conclusions based on any other comparisons that one might be tempted to make with data presented in this report.

Below we outline our basic methodology in greater detail, with particular emphasis on: (1) the HWTF Model; (2) the major components of TRAM; and (3) the data bases that support the analysis, and how these data bases were compiled.

1.3.2 Hazardous Waste Tank Failure Model

The Hazardous Waste Tank Failure (HWTF) Model is a Monte Carlo simulation model that predicts failure events and estimates volumes of released wastes for hazardous waste tanks.[6] Its purpose is to identify the various failure mechanisms associated with hazardous waste tanks, and to predict: (1) the frequency of occurrence of these failure events; and (2) the magnitude of release volumes associated with these events. The model simulates the following failure events:

- Overflows;
- Leaks and ruptures;
- Natural catastrophes;
- Secondary containment failures;
- Operator errors; and
- Detection system malfunctions.

In Monte Carlo simulation, probability distributions are assigned to model variables for which deterministic values are not available. These probability distributions reflect the uncertainty regarding a real value for a particular parameter. The degree to which the model is representative of a particular situation is dependent upon the availability of data for the construction of the probability distribution. Once these distributions are constructed, a value for each variable is randomly chosen from the distribution for that parameter, and a final model prediction is calculated. By repeating this procedure a large number of times, a distribution of predicted values for the final model outcome is constructed. Theoretically, this distribution reflects the combined uncertainties for the different variables contained within the model. Thus, in situations where there is significant uncertainty with respect to values for some model variables, the use of Monte Carlo simulation may be advantageous. However, in some cases the use of Monte Carlo simulation may ascribe greater reliability to model results than is actually warranted due to uncertainty over the choice of probability distributions.

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[6] A detailed description of the HWTF Model is provided in a separate report: Pope-Reid Associates, Inc., Hazardous Waste Tank Failure Model: Description of Methodology, draft report submitted to the Office of Solid Waste, EPA, January 13, 1986.

In the HWTF model, distributions for both the occurrence and timing of failure events are sampled randomly for 250 model iterations. For each iteration, failure events are noted, and release volumes for failure events are calculated. The timing and magnitude of release volumes is reported for each year in which the model has predicted failure to occur. Thus, model output is a set of 250 iterations with each iteration consisting of annual release volumes for the tank operating lifetime considered in the analysis. For this analysis, we used a 20-year time horizon[7] for tanks; therefore, each iteration contains annual release volumes for a total of 20 years. The 250 iterations that are produced by the HWTF model are then sorted using a statistical technique known as cluster analysis, which allows for the selection of five or six representative "release profiles".[8] These profiles are weighted and serve as inputs to the subsurface transport model.

The HWTF model may be used not only to identify the failure events and release volumes associated with different hazardous waste tank technologies, but may also be used to estimate the effectiveness of various protective measures in preventing releases of hazardous wastes to the environment. This use may be accomplished within the model by varying the probability distributions for particular events. However, the model is heavily dependent upon several key assumptions, and is also limited severely by the lack of data for the construction of probability distributions used to estimate the frequency of occurrence and timing of the various events predicted. Important assumptions include the following:

- Tank leaks (with the exception of SQG tanks) are not detected until 25 percent of the throughput for a given tank has escaped. For SQG tanks, 100 percent of the tank throughput must be released before a leak is noticed. These assumptions, made because of a lack of data on this subject, have a large impact on the results of the analysis.

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[7] Because we are interested in simulating releases for tanks representative of the current population of tanks, the initial age of a tank being analyzed by the HWTF model is the median current age of such tanks. This age varies by model tank.

[8] We use the term release profile in this analysis to refer to the set of 20 annual release volumes generated by an iteration of the HWTF model.

- Values are assumed for the mean time to failure for many tank technologies (e.g., concrete tanks) and also for mean time to occurrence for most failure events (e.g., rupture); failure times are assumed to be distributed about these mean values. These values are not strongly supported by data, and have a major effect on the results of the model.

- The model assumes that probability distributions do not change with time. For example, a tank may have a small probability of failure due to localized corrosion until general corrosion thins the tank walls. At that point there is a high probability of a large number of localized corrosion failures. This type of event currently is not accounted for by the model.

Despite these limitations, the HWTF model is currently the only model available that is capable of analyzing the frequency and severity of the failure events associated with hazardous waste tanks under the various regulatory scenarios considered in this analysis. It can be useful for comparing different regulatory scenarios, but its use is more problematic for comparing different tank categories and designs. Chapter 2 provides more detailed documentation of the HWTF model.

1.3.3 Subsurface Transport Model

In the Tank Risk Analysis Model (TRAM), representative release profiles from the HWTF model are input to a subsurface transport model that predicts the transport and environmental fate of contaminants released from hazardous waste tanks in the unsaturated and saturated zones. This transport and fate model was adapted from EPA's Liner Location Risk and Cost Analysis Model[9] (a risk model used to analyze risks for various hazardous waste land disposal options). The model uses the McWhorter-Nelson Wetting Front model to simulate the transport of contaminants in the unsaturated zone, and the Prickett-Lonnquist Random Walk model to simulate saturated zone transport. These models are described briefly below.

McWhorter-Nelson Wetting Front Model. In this model, contaminant transport is represented by the movement of a wetting front generated by the release of liquid from the tank system. The travel time for the wetting front through the unsaturated zone is related to the difference in water content in the layers immediately above and below the wetting front, the distance travelled in the unsaturated zone, the leakage rate (Darcian flux), and the retardation of contaminant flow by soil adsorption.

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[9] Liner Location Risk and Cost Analysis Model, draft report to Office of Solid Waste, EPA, January 1985.

Thus, contaminant transport in the unsaturated zone, as modeled by the McWhorter-Nelson Wetting Front Model, is dependent not only upon properties of the unsaturated zone, but also upon source-specific information (i.e., amount of material released and physical/chemical properties of the released contaminants). In the Tank Risk Analysis Model, we account for the effects of soil parameters by assuming that all tanks are located over a generic unsaturated zone, five meters in thickness, with constant soil moisture, porosity, and permeability throughout. Furthermore, we assume that the fractional organic carbon content (Foc) remains constant throughout the unsaturated zone; therefore, retardation is a function only of the physical and chemical properties of a particular contaminant.

Contaminant retardation and degradation are predicted based on chemical-specific information. Retardation factors for all chemicals included in the TRAM data base (approximately 120 chemicals) are calculated using organic carbon-water partition coefficients (Koc values). Biological and chemical degradation is considered only for those chemicals for which data are available. We used a first-order decay function that accounts for all relevant degradation processes through the first-order constant, k.

The McWhorter-Nelson model has been used extensively in subsurface transport studies and is a well-documented and widely accepted unsaturated zone model. However, to use this model in TRAM it was necessary to make several simplifying assumptions with respect to unsaturated zone conditions and contaminant transport. Although these assumptions tend to oversimplify transport and attenuation processes occurring in the unsaturated zone, they are consistent across all situations and thus allow for direct risk comparisons between different regulatory scenarios to be made. The model, along with its assumptions and limitations, is documented more thoroughly in Chapter 3.

The unsaturated zone model provides as its output a mass loading to the saturated zone for each contaminant released from a particular model tank.

Prickett-Lonnquist Random Walk Model. The Tank Risk Analysis Model uses the Prickett-Lonnquist ground-water transport model with random walk particle tracking to simulate the transport of contaminants in the saturated zone. This model is a numerical (finite difference) model that estimates transport in two dimensions (longitudinal and vertical) and simulates dispersion in two dimensions. It is a widely-used and well-documented ground-water transport model that has been utilized in many ground-water contamination studies.

In TRAM, we do not actually use the Prickett-Lonnquist program code. Instead, TRAM uses a set of "standard breakthrough curves" derived from Prickett-Lonnquist model output to calculate the concentration of a particular contaminant at an exposure well, for a given set of hydrogeologic and mass loading conditions over time. A standard breakthrough curve represents the annual concentration of contaminants at an exposure point due to a release of one kilogram of contaminants.

Hydrogeologic conditions such as horizontal and vertical ground-water velocities, and aquifer configurations and thicknesses are represented in the model by a set of nine generic flow fields that were developed for the Liner Location Risk and Cost Analysis Model. These nine flow fields encompass horizontal ground-water velocities of 1 to 10,000 m/year, and represent single and double aquifers with and without intervening nonaquifer layers. All earth materials in all flow fields are assumed to be homogenous and isotropic.

The transport model has been run for each of the nine generic flow fields. Results for these runs, in the form of "standard breakthrough curves", are used to calculate well concentrations based on mass loadings. These factors are available for three exposure well distances: 60, 600, and 1,500 meters. For comparative purposes, we used the well concentrations for the 60 meter distance. For modeling purposes, the 120 contaminants in the TRAM data base are grouped into four mobility classes based on their retardation coefficients (R_D values). The model uses median values for each group rather than chemical-specific R_D values. Thus, TRAM contains "standard breakthrough curves" for a total of 108 scenarios (nine flow fields x three exposure well distances x four mobility classes).

Although the saturated zone model is considered adequate for comparing the transport of contaminants in hypothetical, generic situations, it should be stressed that the model, as included in TRAM, is not suitable for site-specific analyses. Moreover, developing and using the saturated zone transport model required several simplifying assumptions that affect the model's results and limit its applicability. These assumptions, however, are consistent across all situations, and thus the model is considered useful for comparative purposes. Model assumptions and limitations are discussed in Chapter 3.

Concentrations of contaminants of concern for a particular tank, waste stream, and hydrogeological combination are calculated for exposure wells, located 60 meters from the tank, by the saturated zone model. These concentrations serve as input to the exposure/risk component model of TRAM, which is described in the next section.

1.3.4 Exposure/Risk Model

Subsurface transport model results in TRAM are input to an exposure/risk model, also adapted for TRAM from the Liner Location Risk and Cost Analysis Model. This model estimates the timing and magnitude of exposure to individuals using contaminated ground water as a drinking water source This model also predicts the probability (in terms of a risk estimate) that the exposed individual will suffer an adverse health effect as a result of using the contaminated water supply. In this section, we outline this model briefly.

Exposure Component. To estimate drinking water exposure, we assume that the contaminated water pumped from a well undergoes no treatment, or that treatment is ineffective in removing a significant portion of the contaminant mass contained in the water. Also, we assume that individuals continue to drink the water despite exceedance of taste and odor thresholds, and regardless of noticeable health effects.[10] To calculate exposure, the intake rate of drinking water for humans is assumed to be two liters/day, and the average weight of receptors is considered to be 70 kilograms. One hundred percent absorption of an ingested contaminant is also assumed to occur.

Thus, the yearly dose to an individual using a particular well is considered to be equal to well concentration multiplied by the intake rate of drinking water divided by the receptor weight. In addition to the assumptions noted previously, we also assume that an individual obtains 100 percent of his water from the contaminated well, and that the individual consumes this water over his entire lifetime (population mobility is not considered).

Risk is then calculated for the exposed individual based on the dose and inherent hazard (H), or potency, of the particular chemical to which the individual is exposed. For carcinogens, we used a linear dose-response model (the one-hit model) that assumes no minimum threshold. The model uses EPA unit risk values, when available, to estimate H for carcinogens. For other values, we used H values that were based on fitting the one-hit model to experimental data.

For non-carcinogens, a threshold, or minimum effective dose (MED), is assumed, and a non-linear dose response model (the Weibull equation) is used to calculate risk. Although non-linearity of the dose-response curve may vary somewhat according to the particular chemical of interest, we assume that the shape factor for the dose-response curve, K, is equal to two. H values for non-carcinogens were estimated based on experimental MED values and the frequency response at that dose.

This model is consistent in its approach to calculating carcinogenic risk with the traditional method used by toxicologists and policymakers. The methodology for calculating non-carcinogenic risk diverges from the traditional approach, however, in that it uses derived H values to calculate an explicit risk, rather than using an experimentally determined threshold to estimate an allowable daily intake (ADI). This approach was adopted because the traditional approach is not very useful in explicit risk analyses because it does not allow actual risk values to be calculated.

The primary limitations and assumptions in the risk model are those traditionally found in determining inherent hazards and characterizing dose-response in the low dose regions. Specific sources of uncertainty in the exposure/risk model are described in Chapter 3. It should be noted that the assumptions and limitations inherent to this model make it most useful for comparison purposes, and risks calculated by the model should be considered as relative and not as absolute risks.

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[10] TRAM currently contains taste and odor threshold values for all 120 chemicals in its data base, and the ability to invoke these thresholds is incorporated into the model.

1.3.5 TRAM Data Bases

In order to gain an understanding of the risks associated with hazardous waste tanks through the use of the Tank Risk Analysis Model, it was necessary not only to identify failure events and calculate transport times for a model tank, but to achieve as close an approximation as possible of the real-life situations in which these tanks are found. Thus, we compiled information to develop hazardous waste tank technologies, associated hazardous waste streams, and hydrogeologic settings that are representative of the existing tank population.

In this section, we present brief descriptions of the data bases that were developed in support of TRAM, and discuss their uses within the framework of the analysis.

Model Tank Technology Data Base. To predict tank failure events and release volumes, and to estimate human health risks for the various regulatory scenarios considered in the analysis, we developed a data base containing information on 22 model tank technologies. These model tank technologies were selected to represent typical tanks reported in the OSW Regulatory Impact Analysis (RIA) Tank and Small Quantity Generator Surveys, and encompass four major categories: RCRA-permitted storage tanks, small quantity generator (SQG) tanks, accumulation (less than 90-day storage) tanks, and treatment tanks. Model tanks included in each of these four categories were chosen based on type (i.e., above-ground, in-ground, or underground) and material of construction (i.e., carbon steel, stainless steel, concrete, and fiberglass reinforced plastic).

The model tank data base contains information on tank type, material of construction, and whether a particular model tank is open- or closed-topped. In addition, the data base contains data on the percentage of each category represented by each tank type, and includes median age and size for each of the model tanks. Therefore, although this data base does not represent the extremes that exist in the population of hazardous waste tanks, it contains a representative sample of the tank technologies that are most commonly used to store and treat hazardous waste. The data base is outlined in greater detail in Chapter 4, Section 2.

Waste Stream Data Base. Waste streams most commonly stored or treated in tanks were identified for the four major tank categories considered in the analysis and compiled into a data base containing information on waste stream characteristics (representative constituents and constituent concentrations) and on the percentage of each model tank technology storing each waste stream. In all, 32 waste streams were identified from various data sources as being among those most commonly reported for hazardous waste tanks, and were included in the data base.

Of the 32 waste streams, 10 were identified for SQG tanks, six were selected as being most representative of RCRA-permitted storage tanks, six were identified for treatment tanks, and 12 were identified for accumulation tanks. Thus, there was some overlap between tank categories with regard to waste streams handled, although many wastes identified for SQGs were unique to these tanks. The waste streams encompass a broad range of characteristics, from aqueous wastes containing cyanides and heavy metals to organic solvent waste streams and concentrated substances such as phenol. Therefore, although waste constituents and constituent concentrations for many waste streams may vary markedly from those used in the analysis, the waste stream data base provides a reasonable representation of the wide variety of wastes that are commonly handled in hazardous waste tanks.

Chemical Data Base. Transport and fate information, risk data, and detection limits for 120 hazardous chemicals were compiled in the TRAM chemical data base. This information was taken from the Liner Location Risk and Cost Analysis Model chemical data base, and includes data on both organic and inorganic contaminants. We identified 36 of these chemicals as the most common chemicals handled in hazardous waste tanks.

Transport and fate data in the data base includes aqueous solubility, organic carbon-water partition coefficient (Koc) values, and degradation rate constants for each of the 120 chemicals. Risk information includes unit risk (potency) values for carcinogens and non-carcinogens, and threshold values for non-carcinogens. Type of effect (e.g., cancer, liver damage, etc.) is also identified for each chemical. Chemical detection data includes taste and odor, and detectable concentrations.

This data base does not contain data on all priority pollutants, but does include all of the waste constituents most commonly reported for hazardous waste tanks. The data base is described in greater detail in the EPA Liner Location Risk and Cost Analysis Model draft report.[11]

Hydrogeologic Setting Data Base. As discussed earlier in the chapter, TRAM does not use site-specific hydrogeologic data, but rather considers a model tank to be located in one or more of nine generic flow fields that are believed to represent the range of hydrogeologic conditions that would typically be encountered at tank facilities. This data base contains information on the ground-water velocities and aquifer configurations for each of the nine generic flow fields.

In order to estimate the relative frequency of occurrence of each of these ground-water flow fields for a particular tank category, we distributed the population of model tanks over each state, estimated the percentage of occurrence for each flow field in each state, and from these two distributions calculated the population of each tank category located in each flow field. These data allow for the weighting of the risk estimates associated with the different hydrogeologic settings used in the analysis, and, although it is limited somewhat due to the assumptions necessary in constructing the distribution, it provides some representation of the hydrogeologic conditions that may be encountered at typical tank facilities.

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[11] Liner Location Risk and Cost Analysis Model, draft report to Office of Solid Waste, EPA, January 1985.

The following section briefly outlines the organization of the remainder of the report.

1.4 ORGANIZATION OF THE REPORT

The remainder of this report is organized as follows:

- **Chapter 2 -- Hazardous Waste Tank Failure Model**

  This chapter provides an overview of the model used to simulate the release of hazardous waste over a 20-year time horizon. The chapter focuses on the type of phenomena that the model simulates, rather than the parameters and probability distributions that were used. A more detailed explanation can be found in a separate report.[12]

- **Chapter 3 -- Transport, Exposure and Risk Models**

  This chapter describes the models we used to estimate the transport of contaminants in the unsaturated and saturated zones underlying hazardous waste tanks. The equations and methodology used to estimate chronic human health risks are also presented.

- **Chapter 4 -- Development of Data for Deriving Distributions of Risk Estimates**

  This chapter presents the methodologies and data sources that we used to determine the tank technologies, associated waste streams, and hydrogeologic settings that we should model in order to represent the existing population of hazardous waste tanks. This chapter also presents the methodology we used to develop distributions of risk estimates that are representative of existing tank technologies.

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[12] Pope-Reid Associates, Inc., Hazardous Waste Tank Failure Model: Description of Methodology, draft report submitted to the Office of Solid Waste, EPA, January 13, 1986.

- **Chapter 5 -- Results and Conclusions**

  This chapter reports the results of our current analyses. Results generated from the HWTF Model for the baseline and secondary containment regulatory scenarios are presented in detail. Distributions of risk estimates for every combination of modeled tank technology and regulatory scenario are presented and discussed.

- **Appendix A -- Failure Frequency Data and Representative Release Profiles**

  The appendix presents all the representative release profiles that we used to generate risk estimates for each modeled tank technology and regulatory scenario.

- **Appendix B -- Supplementary Analysis of Eleven Regulatory Scenarios**

  This appendix presents the results of a supplementary analysis of eleven regulatory scenarios. The major objective of this analysis was to directly compare different regulatory scenarios for a single situation (i.e., model tank, waste stream, and hydrogeologic setting) rather than for the population of existing tanks.

CHAPTER 2

HAZARDOUS WASTE TANK FAILURE MODEL

In this chapter we discuss the Hazardous Waste Tank Failure Model. We used this model to generate estimates of the timing and magnitude of releases from hazardous waste tanks over a 20-year time horizon. The purpose of the model is to simulate the timing and magnitude of various types of tank failures (e.g., leaks, ruptures, etc.) associated with hazardous waste tank technologies based on each of the five regulatory scenarios. The model estimates a potential range of annual release volumes associated with the hazardous waste tanks. A simulated series of annual release volumes for a particular tank technology is used as input to the Tank Risk Analysis Model.

In the first section of this chapter we provide a general overview of the HWTF model. In Section 2.2 we present the representative tank technologies that we modeled. Section 2.3 identifies various leak detection and prevention options that were used to model each regulatory scenario. In Section 2.4 we discuss how we characterized the environment surrounding hazardous waste tanks, and then in Section 2.5 we describe the generic waste streams that we used for modeling purposes. Finally, in Section 2.6 we present the types of events that were simulated and the release volumes associated with each event.

2.1 OVERVIEW OF HAZARDOUS WASTE TANK FAILURE MODEL

The release of hazardous waste from treatment and storage tanks is contingent on the occurrence of one or more failure events, many of which have a degree of uncertainty associated with them. Consequently, we used a model that can account for these uncertainties. The HWTF model is based on the principles of probability and statistics and can simulate particular aspects of phenomena that relate to the release of hazardous waste from tanks. This type of model, generally referred to as a Monte Carlo simulation model, permits us to evaluate the potential range of releases from tanks.

Exhibit 2-1 illustrates one representative series of annual release volumes simulated by the model.[2] This series of releases constitutes one potential release profile associated with a tank. For this study, we used the model to generate 250 representative series of annual release volumes.[1] A release profile is based on four major factors: (1) timing of events; (2)

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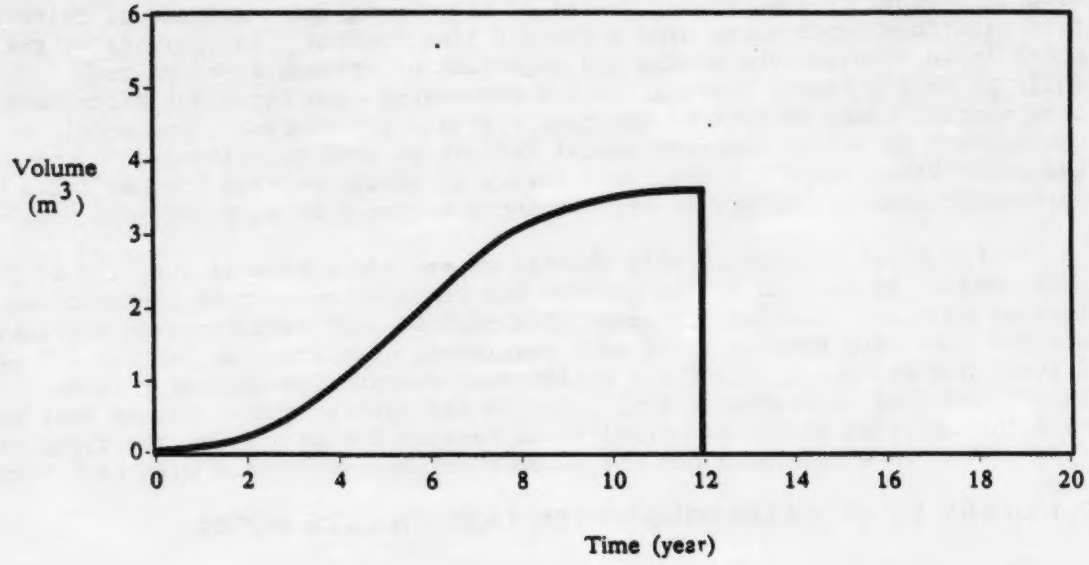
[1] Although the choice of the number of estimates (i.e., release profiles) generated by a Monte Carlo model is traditionally based on the statistical analysis of the convergence properties of the estimates, this analysis was not done for this study. Basically, the choice to generate 250 profiles was based on professional judgment and cost constraints.

[2] For this release profile, the release was detected in year 12 and the tank was replaced. No subsequent releases occured following replacement of the tank.

EXHIBIT 2-1
POTENTIAL RELEASE PROFILE



magnitude of release volumes; (3) duration of release; and (4) detection of release. The model evaluates each of these factors using probability distributions that represent the phenomena we are modeling. For example, the occurrence of a tank rupture is based on probability distributions representative of the ways in which a tank can rupture. The types of events (i.e., phenomena) that we modeled can be categorized as follows:

- Overflows;
- Corrosion of the tank and/or pipes;
- Rupture of the tank and/or pipes;
- Natural catastrophes;
- Spills;
- Effectiveness of protective measures; and
- Effectiveness of detection measures.

The model first simulates the occurrence of events that can lead to the release of hazardous waste. The ability of protective measures to prohibit the release from occurring is then simulated. For example, the effectiveness of an emergency shut-off control system to prevent an overflow is simulated. If the release is not prevented, a leak rate is simulated. This leak rate is modeled to continue until the release is detected. The detection of a release is based on when an available inspection option is simulated to be effective.

Obviously, whether or not a protective measure prevents a release depends on what protective measures (e.g., secondary containment) are available and the effectiveness of the measures. Similarly, the detection of releases, depends on the frequency and effectiveness of inspections. In a sense, the protective and detection measures are the focus of this analysis because they are used to define each regulatory scenario. Consequently, we discuss in this chapter the assumptions that we used to model each of the regulatory scenarios in terms of the simulated protective and detection measures. In the next section we present the hazardous waste tank technologies that we modeled. We then present the protection and detection measures that we modeled for each regulatory scenario. In the last section we discuss the failure events that the model simulates. A more detailed discussion of the probability distributions and leak rate equations used to model the failure events is presented in a separate report.[3]

2.2 TANK TECHNOLOGIES

Clearly, one basic requirement for an assessment of failures of and releases from hazardous waste tanks is the selection of representative hazardous waste tank technologies. We divided the universe of hazardous waste tanks into four categories: RCRA permitted treatment tanks, RCRA permitted storage tanks, accumulation tanks (storage for less than 90 days), and small quantity generator (SQG) tanks. Tanks can be distinguished further by their location (e.g., above-ground, inground, or underground) and their material of construction (e.g., concrete, carbon steel, stainless steel, or fiberglass-reinforced plastic). Using survey data, we selected 22 representative tank technologies (details of this selection process are presented in Section 4.2). The characteristics of these tank technologies are shown in Exhibit 2-2 and their operating parameters are shown in Exhibit 2-3. For each tank technology we also identified a median age and size.* These characteristics are used to simulate the existing tank population. The remainder of this section provides specific details on the tank technologies that we modeled.

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[3] Pope-Reid Associates, Hazardous Waste Tank Failure Model: Description of Methodology, draft report to the Office of Solid Waste, EPA, January 13, 1986.

2.2.1 Treatment Tank Systems

We selected two treatment processes, oxidation/reduction/precipitation and distillation, to represent hazardous waste treatment tanks in this analysis. In this section we describe each of these processes and the modeled design specifications.

Oxidation/Reduction/Precipitation

We modeled oxidation/reduction/precipitation as a continuous process using three tanks. We modeled five different types of oxidation/reduction/precipitation treatment technologies. These tanks differ in their location (e.g., above-ground, in-ground) and material (e.g., carbon steel, concrete, stainless steel) A diagram of the oxidation/reduction/precipitation process is presented in Exhibit 2-4. Only aqueous waste streams were assumed to be treated by this process.

The first tank is used to adjust the pH of the influent waste stream to optimize the oxidation/reduction/precipitation reactions that will occur in the second tank. The waste is pumped into the top of the tank at a rate that is equal to the operating capacity of the tank divided by the retention time, (the length of time the fluid is kept in the tank to complete reactions and mixing). We assumed that the waste has a thirty minute retention time in the first tank. We also assumed that the fluid depth in each tank is maintained at 80 percent of the tank height.

The second tank is used for oxidation, reduction, or precipitation, depending upon the characteristic of the waste being treated. This tank is four times as large as the first tank to allow for a two hour retention time.

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* We used the median tank age to simulate the conditions of the existing tank population. For example, for in-ground, concrete, treatment tanks, we simulated these tanks to have been in operation for the past 7 years (with respect to model year 1). Some of these tanks have started to corrode and may be leaking today (i.e., in model year 1) or are likely to develop leaks within the next few years. Consequently, in model year 1, tanks may be simulated to be releasing undetected hazardous waste or to be corroding.

EXHIBIT 2-2

CHARACTERIZATION OF EXISTING HAZARDOUS WASTE TANKS

Median Size (gallons)	Tank Location a/	Material of Construction b/	Tank Top	Pipe Location	Median age (years)	Wall Thickness (inches)
TREATMENT:						
2,300	Above-ground, on cradles	Carbon steel	Closed	above-ground	5	.25
2,300	Above-ground, on cradles	Carbon steel	Open	above-ground	5	.25
60,000	Above-ground, ongrade	Carbon steel	Open	above-ground	9	.50
3,700	In-ground	Concrete	Open	above-ground	10	8.00
3,700	In-ground	Carbon steel	Open	above-ground	10	.25
3,700	In-ground	Stainless steel	Open	above-ground	10	.25
STORAGE:						
5,500	Above-ground, on cradles	Carbon steel	Closed	above-ground	6	.25
210,000	Above-ground, ongrade	Carbon steel	Closed	above-ground	21	.625
4,000	Underground	Carbon steel	NA	underground	7	.25
4,000	Underground	FRP	NA	underground	7	NA c/
4,000	Underground	Stainless steel	NA	underground	7	.25
2,100	In-ground	Concrete	Open	above-ground	8	6.00
2,100	In-ground	Carbon steel	Open	above-ground	8	.25
SMALL QUANTITY GENERATORS:						
200	Above-ground	Carbon steel	Closed	above-ground	6	.25
200	Underground	Carbon steel	NA	underground	7	.25
ACCUMULATION:						
5,500	Above-ground, on cradles	Carbon steel	Closed	above-ground	6	.25
210,000	Above-ground, ongrade	Carbon steel	Closed	above-ground	21	.625
4,000	Underground	Carbon steel		underground	7	.25

EXHIBIT 2-2 (continued)

CHARACTERIZATION OF EXISTING HAZARDOUS WASTE TANKS

Median Size (gallons)	Tank Location a/	Material of Construction b/	Tank Top	Pipe Location	Median age (years)	Wall Thickness (inches)
4,000	Underground	FRP		underground	7	NA c/
4,000	Underground	Stainless steel		underground	7	.25
2,100	In-ground	Concrete	Open	above-ground	8	6.00
2,100	In-ground	Carbon steel	Open	above-ground	8	.25

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a/ Inground tanks are assumed to be 50 percent below-ground and 50 percent above-ground.

b/ Pipe is constructed of the same material as the tank for all technologies except concrete tanks, which have carbon steel pipes.

c/ Tank thickness is not specified for FRP tanks because all failure events are modeled to be independent of tank thickness.

Source: Median size, tank location, material of construction and median age are based on OSW RIA Tank Survey. Pipe location and wall thickness are based on engineering judgment.

EXHIBIT 2-3

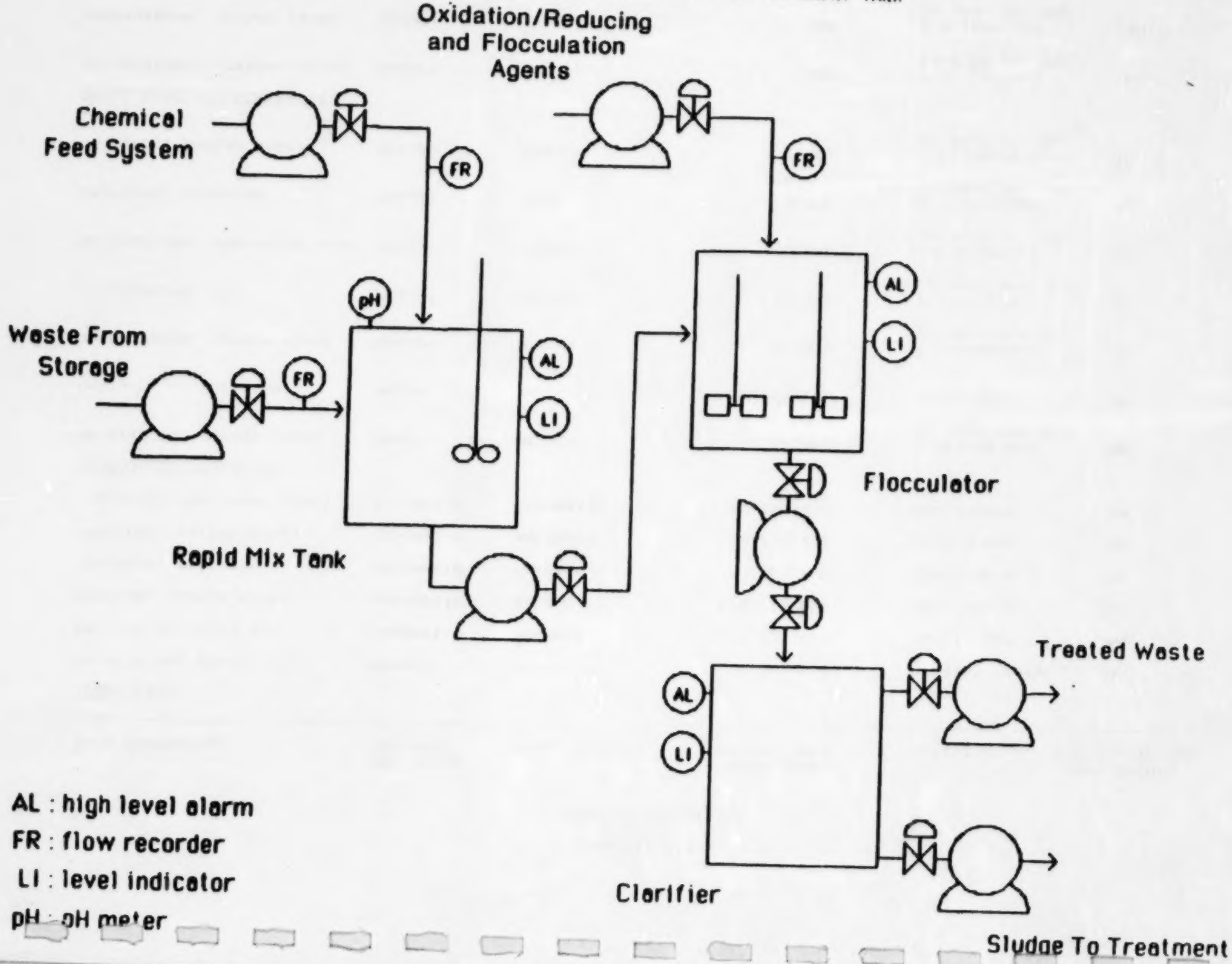
OPERATING PARAMETERS

Tank Technology	Emergency Shut-Off	Level Control	Throughput (gallons/yr)	Operation	Days Before Tank is Emptied
TREATMENT:					
On cradles, closed top	Manual	Manual	2,852,000	4 batches/day	NA
On cradles, open top	Automatic	Automatic	18,252,000	Continuous	NA
Ongrade, carbon steel	Automatic	Automatic	476,160,000	Continuous	NA
Inground, concrete	Automatic	Automatic	29,363,200	Continuous	NA
Inground, carbon steel	Automatic	Automatic	29,363,200	Continuous	NA
Inground, stainless steel	Automatic	Automatic	29,363,200	Continuous	NA
STORAGE/ACCUMULATION:					
On cradles, carbon steel	Manual	Manual	22,000	2 discharges to tank per day	90
Ongrade, carbon steel	Automatic	Manual	6,200,000	Continuous	NA
Underground, carbon steel	Manual	Manual	16,000	2 discharges to tank per day	90
Underground, FRP	Manual	Manual	16,000	2 discharges to tank per day	90
Underground, stainless steel	Manual	Manual	16,000	2 discharges to tank per day	90
Inground, concrete	Manual	Manual	8,400	2 discharges to tank per day	90
Inground, carbon steel	Manual	Manual	8,400	2 discharges to tank per day	90
SMALL QUANTITY GENERATOR:					
Above-ground, carbon steel	Manual	Manual	400	2 discharges to tank per day	180
Underground, carbon steel	Manual	Manual	400	2 discharges to tank per day	180

Source: Operating parameters are based on engineering judgment.

EXHIBIT 2-4

OXIDATION/REDUCTION/PRECIPITATION TREATMENT TANK


Oxidation/Reducing and Flocculation Agents
Chemical Feed System
FR
FR
pH
Waste From Storage
FR
AL
LI
AL
LI
Rapid Mix Tank
Flocculator
Treated Waste
AL
LI
Clarifier
Sludge To Treatment
AL : high level alarm
FR : flow recorder
LI : level indicator
pH : pH meter

Following this reaction, another reagent may be added to enhance precipitation of the waste constituents. We assumed that the pH-adjusted waste from the first tank is pumped into the second tank at the same rate it is pumped into the first tank. In this tank, an oxidizing or reducing agent that will render some component of the waste non-hazardous is added. A flocculating agent is also added. We assumed that no reactions or phase changes occur in the reactor except for those pertaining to the destruction of the hazardous constituents. Also, we assumed that destruction of the hazardous constituent from both dissolved and suspended portions occurs and that destruction products are non-hazardous. No appreciable volume change is assumed due to the addition of reagent chemicals.

The third tank is used for clarifying the waste. This tank was modeled as being eight times the size of the first tank to allow for a four hour retention time. The waste containing the flocculating agent is pumped into the third tank at the same rate that the waste is pumped into the first tank. In the third tank the clarifier requires a four hour retention time to clarify the waste. We assumed that all of the dissolved hazardous constituents are removed to the suspended solids phase upon the addition of the flocculating agent. We assumed that the effluent from the clarifier contains no suspended solids and that all suspended solids and all coagulant chemicals are carried out with the underflow waste volume. We assumed that the underflow waste volume removes half of the liquid entering the third tank, and consequently the discharge rates for the effluent and underflow are equal (i.e., each rate is half the fill rate).

Distillation

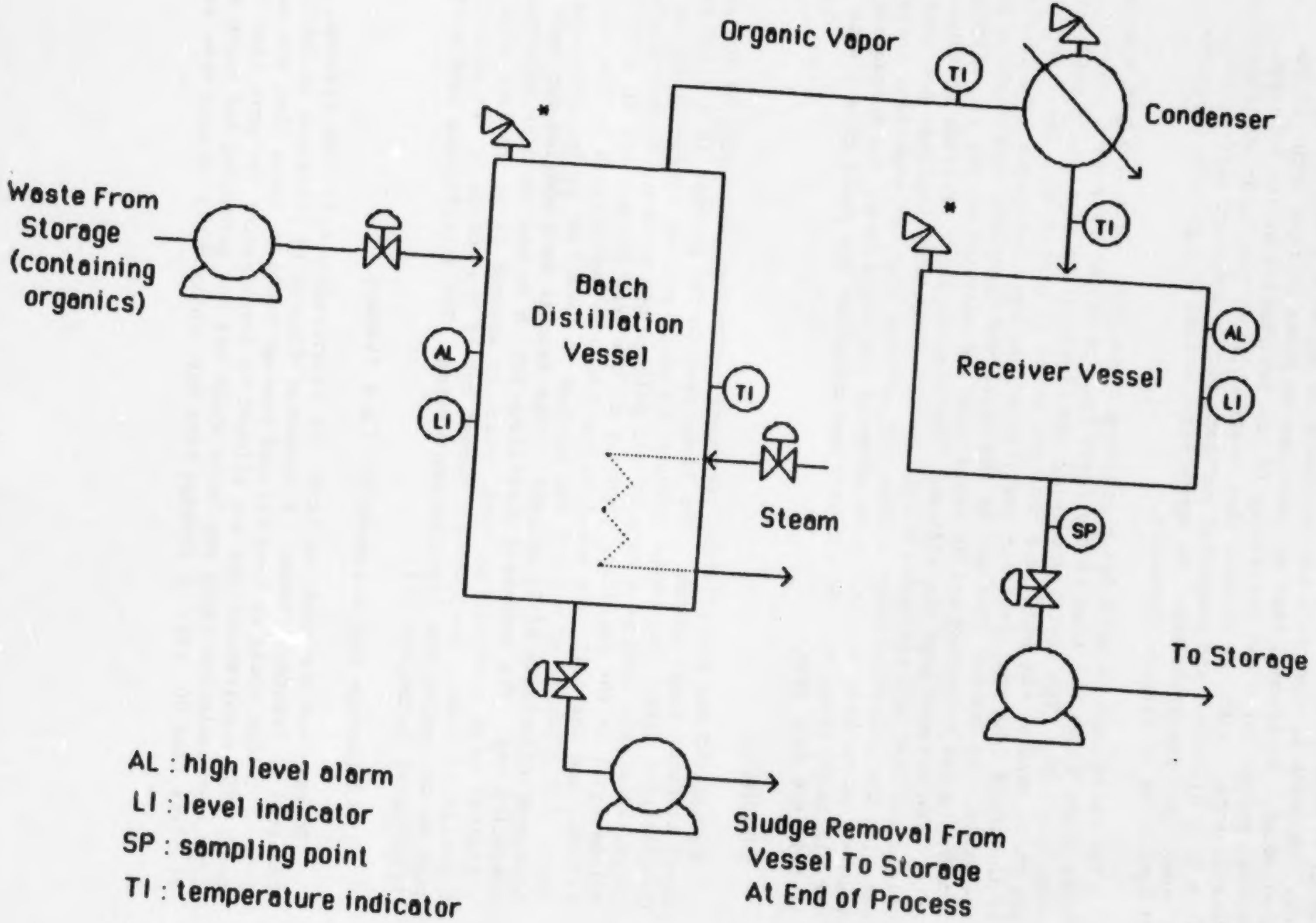
We modeled one distillation treatment technology consisting of two carbon steel tanks of equal volume. The first tank in the process is a 2,300 gallon distillation tank. The waste (assumed to be 50 percent concentrated) is pumped into this tank at a rate of 100 gallons per minute. We set the batch volume equal to the operating capacity of the tank (80 percent of 2,300 gallons) and the fill time equal to the batch volume divided by the pumping rate. Distillation of a batch was assumed to take four hours, resulting in a treatment efficiency of 90 percent. Four batches were modeled for each operating day. The condensed distillate (which is now pure) is subsequently collected in an accumulation tank, which is assumed to be the same size as the distillation tank. Residues are pumped out of the bottom of the distillation tank at the end of the distillation process. The distillation tank system is illustrated in Exhibit 2-5.

2.2.2 Storage and Accumulation Tank Systems

Storage and accumulation tanks are relatively simple tank systems, compared to treatment tanks. A schematic diagram is presented in Exhibit 2-6. For this study we have defined storage tanks as tanks that are permitted under RCRA requirements and are allowed to store wastes for more than 90 days. Accumulation tanks are tanks which are not permitted and store wastes for less than 90 days. A storage tank may continuously contain some waste,

EXHIBIT 2-5

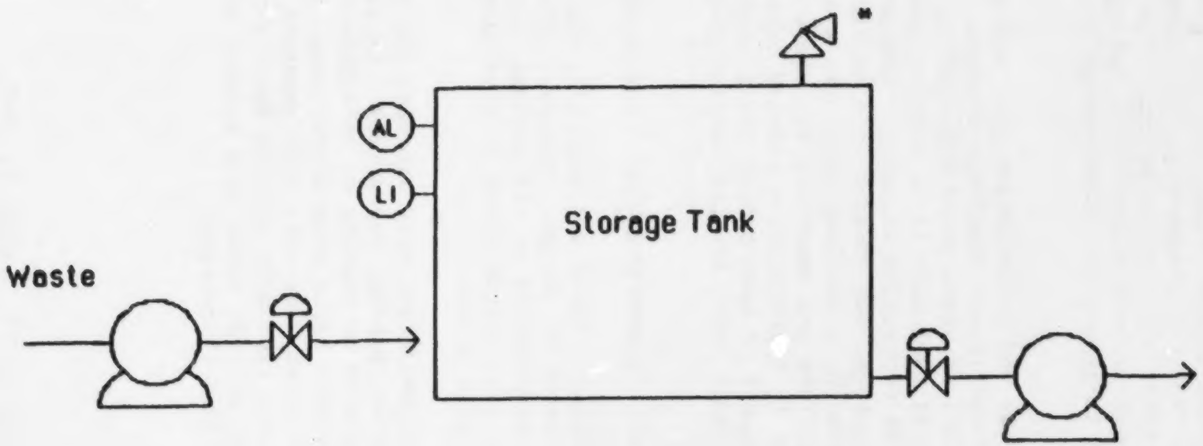
DISTILLATION TREATMENT TANK


Organic Vapor
TI
Condenser
Waste From Storage (containing organics)
Batch Distillation Vessel
AL
LI
TI
Steam
TI
Receiver Vessel
AL
LI
SP
To Storage
Sludge Removal From Vessel To Storage At End of Process
AL : high level alarm
LI : level indicator
SP : sampling point
TI : temperature indicator

* Closed tank is also equipped with an overflow valve.

EXHIBIT 2-6

STORAGE TANK


Waste
AL
LI
Storage Tank
*

AL: high level alarm

LI: liquid level indicator

* Closed tank is also equipped with an overflow valve.

but an accumulation tank must be completely emptied at least every 90 days. However, data indicate that, in actuality, both storage and accumulation tanks are used to store waste for approximately 90 days. Because the designs of these two types of tanks are so similar, they have not been modeled separately.

Storage and accumulation tank systems consist of three basic elements: a fill and discharge system (either using pumps or gravity feed), piping, and the tank itself. The tank may be above-ground, in-ground, or underground and may vary in size and material of construction. The pipes may be above-ground or underground (although we have assumed that underground tanks have underground pipes and in-ground and above-ground tanks have above-ground pipes).

Two types of storage and accumulation tank systems were modeled: batch discharge systems and continuous discharge systems. For batch systems, we assumed that two batches of waste are discharged to the tank each operating day and that the tank is full when it is emptied every 90 days. The flow of waste was assumed to be controlled manually. One accumulation/storage tank, a 210,000 gallon ongrade tank, was modeled as a continuous discharge system. This tank was assumed to be a settling tank with a 5-day retention time. We assumed that 20,000 gallons per operating day are pumped into and out of the tank and that the tank is operated at a reduced capacity of 100,000 gallons. This tank was also assumed to have manual level controls because minor fluctuations of the liquid level are not crucial when the tank is operating at 50 percent capacity.

2.2.3 Small Quantity Generator (SQG) Tank Systems

Small quantity generator tanks are basically the same as storage and accumulation tanks in terms of design. However, storage time has been assumed to be 180 days, which corresponds to the maximum time allowed in the proposed SQG regulations for on-site accumulation by SQGs without being required to obtain interim status or a permit.[5]

Like storage and accumulation tank systems, SQG tank systems consist of a fill and discharge system, piping, and a tank. We assumed that SQG tanks are either located above-ground on cradles or underground, and are constructed of carbon steel. Above-ground tanks have above-ground pipes and underground tanks have underground pipes. Because they generate small amounts of waste, small quantity generators typically utilize small capacity tanks. For purposes of this study, all SQG tanks were modeled to be 200 gallons (see Section 4.2 for a detailed discussion).

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[5] 50 Federal Register 31278, August 1, 1985.

2.3 PROTECTION AND DETECTION OPTIONS

In this section we describe the modeled protection and detection measures associated with each tank technology. Basically, tank facility operators can employ a number of design options and operating procedures to reduce the possibility of a release from a tank system or to minimize the duration of a release. We have incorporated a number of these preventive measures into the HWTF model. These measures include:

- Inventory control;
- Emergency shut-off control systems;
- Visual inspection;
- Leak testing;
- Secondary containment; and
- Cathodic protection.

Once releases are detected, they are minimized by prompt replacement of failed components. We assumed that if a leak in a particular component is detected by a visual inspection, then that component alone is immediately replaced. Similarly, when leaks are detected by leak tests or other monitoring methods (e.g., inventory control), we assumed that only failed components are replaced. Tank failures resulting from environmental catastrophes, however, would entail replacement of all components. We describe each of these measures in the following sections.

2.3.1 Inventory Control

We assume that, hazardous waste tank operators can detect major shortfalls (i.e., leaks) in the quantity of stored waste from caused inventory (i.e., normal filling and discharging operations). We are uncertain of the effectiveness of inventory control for detecting small leaks from hazardous waste tanks. However, we assume that relatively large losses of tank liquid would be noticed by an operator during normal operations.

We are uncertain of the percent of the tank operating capacity such that a shortfall will be detectable by casual inventory monitoring. Nevertheless, we have assumed that a loss of 25 percent or more of the tank contents would be detected for treatment, storage, and accumulation tanks. The modeled SQG tanks are considerably smaller than the other modeled technologies, and even at 25 percent of the capacity of a SQG tank, shortfalls may not be detected. Consequently, we have assumed that 100 percent of the SQG tank contents must be released for a leak to be detected.

The algorithm we used to model detection over-simplifies the actual detection process. In actuality, the detection of releases is likely to be dependent on an operator's attention to tank operation (i.e., the operator knows the time required to fill/empty the tank), leakage rate (i.e., if the leakage rate is greater than the fill rate, the operator would notice that the tank is not filling up), general inspection procedures (i.e. an open top tank is likely to be inspected daily in order to prevent overflows), type of tank category (i.e. small quantity generators are in more populated areas (parking lots) than treatment tanks where leaks are more likely to be noticed), and tank technology (i.e., releases from above-ground tanks are more likely to be detected than releases from underground tanks. Although our simple approach does not explicitly incorporate all these factors, other types of modeled inspections do incorporate some of these factors. For example, casual visual inspections of above-ground tank components will result in the detection of releases greater than 250 cm^3/sec (see section 2.3.3). For all tanks, except SQG tanks, we assumed 25 percent of the tank contents must be released for a release to be detected. Although the detection threshold associated with SQG tanks is probably less than 100 percent, we could not identify a more reasonable threshold, and so we chose to use a conservative assumption of 100 percent. In general, for above-ground SQG tanks, releases were detected prior to the release of 100 percent of the tank contents. However, for underground SQG tanks, the modeled method for detection required that 100 percent of the tank contents be released prior to detection.

These thresholds apply to the sum of all losses occurring during the inventory period. For example, if a tank has two leaks, neither of which is large enough to trigger detection, their sum may nevertheless exceed the threshold level, and both leaks would then be detected. However, as casual inventory monitoring is modeled, it is generally ineffective for treatment tanks and continuous throughput storage or accumulation tanks, because the large throughputs of these tanks mean that any leaks large enough to cause detectable shortfalls would also be large enough to be immediately obvious to the operator.

Different tank systems are monitored on different cycles. Open-topped tanks are assumed to be reconciled once a month, while storage and accumulation tanks are generally reconciled whenever they are pumped out. Continuous throughput storage tanks (settling tanks) are monitored once a month, even if they are closed-topped. The monitoring (inventory control) cycles for each tank technology are shown in Exhibit 2-7.

As an example of how releases are detected by inventory control monitoring, consider two hypothetical tank systems. One is a closed-topped storage tank pumped-out semi-annually, the other an open-topped settling tank pumped-out on a monthly basis. Assume that both tanks have a monthly throughput of 50,000 gallons. For inventory control to detect a leak in the first tank, the size of the leak would have to exceed .25 x 50,000 gallons/month x 6 months = 75,000 gallons over a six-month period. In the second example, the size of the leak would have to exceed .25 x 50,000 gallons/month x 1 month = 12,500 gallons over a one-month period. Note that the detectable leak rates for these two tanks are the same (in gallons per month), but that the leak of the second tank would be detected much earlier than the leak in the first tank.

2.3.2 Emergency Shut-off Systems

Emergency shut-off systems are a means of preventing overflow events by stopping the inflow of waste into the tank. We modeled two types of emergency shut-off systems: manual systems and automatic systems with manual backup

EXHIBIT 2-7

INVENTORY CONTROL CYCLES

Tank Technology	Monitoring Cycle
TREATMENT:	
on cradles, carbon steel, closed top	1 month
on cradles, carbon steel, open top	1 month
ongrade, carbon steel	1 month
in-ground, concrete	1 month
in-ground, carbon steel	1 month
in-ground, stainless steel	1 month
STORAGE/ACCUMULATION:	
on cradles, carbon steel	90 days
ongrade, carbon steel	1 month
underground, carbon steel	90 days
underground, fiberglass-reinforced plastic	90 days
underground, stainless steel	90 days
in-ground, concrete	1 month
in-ground, carbon steel	1 month
SMALL QUANTITY GENERATORS:	
on cradles, carbon steel	180 days
underground, carbon steel	180 days

systems. Manual systems consist of a high level sensor and an alarm which signals the operator to manually turn off the inflow pump or shut the inlet valve if the high-level sensor is activated. Automatic shut-down systems consist of a high-level sensor connected to a microprocessor which shuts down the inlet pump and valve. If the inlet system fails to shut down, the microprocessor adjusts the outlet pump and valve to increase the rate of outflow.

We applied manual emergency shut-off systems to tanks with batch processes, and applied automatic emergency shut-off systems to tanks with continuous processes. These choices seem logical since an operator is available to respond to an alarm for batch process tanks, while there often is no operator present for continuous process tanks.

Both of the automatic and manual shut-off systems are subject to failure. For tank systems with automatic shut-down systems (i.e., continuous treatment processes), the high level sensor may fail or pumps and valves may not respond to signals sent by the system to shut down. We assumed a failure probability of 0.11 per year for automatic shut-off systems. This value is based on available data for capacitance type level transducers. Manual shut-down systems fail if an operator does not respond to an overflow alarm condition. We assumed that the probability for operator error is 0.03, based on available reliability data. It is also possible for the alarm to malfunction. The failure probability of the alarm was assumed to be 0.1 per demand, also based on available reliability data.

2.3.3 Visual Inspections

The Hazardous Waste Tank Failure Model simulates three types of inspections. One of these is a casual "walk-around" inspection of above-ground portions of tank systems, which we assume occurs daily at all facilities. Another is a more thorough weekly inspection of above-ground tanks and piping which reflects current regulatory requirements.[6] In addition, we assumed that during installation of tanks, inspections are conducted to detected any deficiencies in the tank components. The probability of detecting a leak depends upon the leak rate, and is different for each type of inspection. The general assumptions we used to model the effectiveness of each type of visual inspection are the following:

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[6] For the baseline scenario, we modeled above-ground SQG tanks to be inspected only monthly, because SQG tanks are not subject to current regulations. For the other regulatory scenarios, we modeled above-ground SQG tanks to be inspected weekly.

- **Casual inspection.** We assumed that casual inspections will always be sufficient to immediately detect a leak larger than a running faucet (approximately 250 cm^3/sec). For leaks with rates between 1 drop per second (approximately .05 cm^3/second) and 250 cm^3/second, we have assumed the probability of detection is 50 percent. Smaller leaks will not be detectable by this method.

- **Weekly inspection.** Weekly inspection is modeled to have a 95 percent chance of detecting any above-ground leak (and a 100 percent chance of detecting leaks of over 250 cm^3/sec).

- **Installation inspection.** Installation inspections are simulated when tanks or tank components are replaced. Under all regulatory scenarios, except leak testing combined with groundwater monitoring, we simulated installation inspections to consist of a visual inspection and weld testing. We assumed this procedure to be 75 percent effective in detecting a damaged component. Under the regulatory scenario for leak testing combined with groundwater monitoring. We assumed that, in addition to visual inspection and weld testing, leak testing would also be conducted after tank installation. This inspection procedure was assumed to catch 95 percent of installation defects.

2.3.4 Leak Testing

We simulated leak testing, in combination with ground-water monitoring, for only one of the regulatory scenarios that we are analyzing. Leak testing is applicable only to underground tanks and is usually performed by a contractor experienced in the procedure. Currently, several methods are commercially available, although their applicability to hazardous waste tanks is not well documented. As a result, for this analysis we assumed that the tank is emptied, cleaned, and filled to capacity with water. The water in the tank is then monitored by a sensitive device which records any changes in the hydrostatic pressure at a fixed depth within the tank.

We simulated leak testing every six months. This six month frequency of testing is consistent with the time period prescribed in the Agency's proposed regulations. Leak testing was modeled to be 100 percent reliable in detecting leaks that exceed a pre-determined threshold. We used a threshold of 0.1 gallons per hour. When a leak is detected, we assumed that the tank is replaced.

2.3.5 Secondary Containment

Our assumptions concerning secondary containment for the full and partial secondary containment regulatory scenarios are shown in Exhibit 2-8.

EXHIBIT 2-8

SECONDARY CONTAINMENT ASSUMPTIONS

Tank Location	Containment Method Full Secondary Containment Scenario	Partial Secondary Containment Scenario
Underground	Tank: double-walled Pipe: double-walled	NA
In-ground	Tank: double-walled with concrete pad and berm surrounding tank Pipe: concrete-lined trench	Tank: concrete pad and berm surrounding tank Pipe: concrete-lined trench
Above-ground, on cradles	Tank: concrete pad and berm Pipe: concrete-lined trench	Same as secondary containment.
Above-ground, ongrade	Tank: concrete pad and berm (pad underneath tank) Pipe: concrete-lined trench	Tank: concrete pad and berm (pad not underneath tank) Pipe: concrete-lined trench

Secondary containment systems are designed to prevent the release of fluids from the primary containment system (the tank) to the surrounding environment. Although other containment options are available, we believe that the ones we selected are representative secondary containment methods that would reflect future practices. In general, underground components and in-ground tanks are assumed to be double-walled, and above-ground components are assumed to have a concrete pad and berm (tanks) or concrete trench (pipes) beneath them. Ongrade tanks are assumed to be built on top of a concrete pad.

In the case of double-walled tanks and pipes, we simulate continuous monitoring of the interstitial space by means of a conductivity-type sensor. We assumed that the liquid sensor has a 90 percent chance of detecting a leak of any size and can detect breaches in both the inner or outer walls of the tank and pipe components. Releases contained by above-ground secondary containment are detected during routine daily inspections.

Although secondary containment systems are designed to prevent all releases from the primary containment from entering the environment, there is still a chance that releases may occur. Double-walled tanks and pipes are still subject to the same corrosive forces as single-walled tanks and pipes. Howver, because the interstitial monitoring device can detect liquids entering from a leak in the primary or the secondary containment wall, a release occurs only if the monitoring device and both walls fail simultaneously. Above-ground concrete pads and berms are subject to cracking and deterioration with age. If a concrete pad and berm system is in a failed state at the time of a primary containment failure, we assumed that the release volume is equivalent to that from a tank system with no secondary containment. In addition, external catastrophes may also breach secondary containment. External catastrophes which may breach secondary containment are the same as those which may breach the tank system itself. Because these events usually involve serious structural damage to the entire tank facility, we have assumed that whenever such catastrophes breach one containment system, they also breach the other. Therefore, release volumes associated with catastrophic failures are the same for tanks with and without secondary containment.

2.3.6 Cathodic Protection

Cathodic protection is a method to prevent corrosion of metal tank and pipe systems in contact with the soil. We modeled the impressed current type of cathodic protection because it can be retrofitted without excavation of the tank. For this type of protection, underground portions of tanks and ancillary pipes are connected to a continuous electrical current to prevent the electrochemical reactions leading to corrosion from occurring. Properly installed and maintained, cathodic protection systems should prevent corrosion indefinitely. However, they require regular monitoring, and prompt repair or replacement of failed components.

According to the National Association of Corrosion Engineers, the leading cause of cathodic protection failure is failure to conduct scheduled maintenance. For this reason, we simulate the quality of maintenance using a random multiplicative factor. We simulated the year of failure of cathodic protection systems using an assumed normal distribution with a mean of 10 years and a standard deviation of five years. The multiplicative factor is a random number between one and three. A value of one means that no maintenance is undertaken; a value of three indicates that the operator carefully follows the prescribed maintenance schedule. This number is multiplied by the sampled time to failure, and serves to delay failure for well-maintained systems.

Once cathodic protection fails, the tank begins to corrode in the same manner as a new, unprotected tank. However, we assume that there is an annual probability of 0.95 that the cathodic protection system is detected to be in a failed stated and is consequently repaired. Following repair, exterior and interior corrosion terminates and a new time to failure of the cathodic protection system is sampled.

2.4 CHARACTERIZATION OF SURROUNDING SOIL

The soil in contact with a tank influences the rate of corrosion of tank components in contact with the soil, and the leak rates of contaminants released from underground tank system components (e.g., piping). We simplified our approach by modeling only one representative soil type. We assumed that the soil in contact with underground and on-grade tank systems consists of a uniform sand. Sand was chosen because it is an abundant subsurface material, comprising glacial deposits, alluvial materials, and coastal plain sediments. Consequently, it is typical of many areas of the country. We also assumed that sand is used as the backfill material for underground tanks, which is a common practice for tank installations.

Leak rates from underground tanks and pipes are affected by several different soil parameters, including the void fraction of the particles, soil particle diameter, the sphericity of the soil particles, and the distance required for leaking fluid to disperse to a point at which its pressure equals that of the pore space in the surrounding soils (dispersion length). The basic soil parameters were readily available from hydrogeologic texts, but dispersion lengths were not available for underground leaks. Thus, we had to estimate dispersion lengths based on best engineering judgment.

For purposes of determining corrosion rates, sandy soil can be classified as benign, or, non-aggressive. There are four basic parameters that determine the aggressiveness of soil: pH, the presence of sulfides, soil moisture, and resistivity. We assumed that the soil surrounding underground tanks and pipes is a benign soil that has a pH of 6 (slightly acidic), has no sulfides, is unsaturated, and has a resistivity of 15,000 ohm/cm. A summary of the soil parameters we used is given in Exhibit 2-9.

2.5 CHARACTERIZATION OF WASTE STREAM PHYSICAL PROPERTIES

The physical properties of waste streams handled in tanks influence the leakage rates for releases from underground, ongrade, and in-ground tanks. In order to reduce the number of necessary HWTF Model runs, we categorized the 32 model waste streams (i.e., the waste streams we have selected for this

EXHIBIT 2-9

SOIL PARAMETERS FOR SAND

Parameter	Value
Void fraction	.53 (dimensionless)
Particle diameter	.25 millimeters
Sphericity	.65 (dimensionless)
Dispersion length (cm)	
circular holes a/	20 x hole diameter
elongated cracks b/	40 x crack width
pH	6
Sulfides	none
Resistivity	15,000 ohm/cm

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a/ Dispersion length limited to a maximum of 20 centimeters.

b/ Dispersion length limited to a maximum of 40 centimeters.

study) according to their physical properties.[7] Because viscosity and density are the physical properties that influence leakage rates, we chose two representative waste streams that differ in these properties and are representative of the waste streams we examined in this study. We selected toluene and aqueous solutions of heavy metals and/or cyanide to represent the range of physical properties associated with the 32 model waste streams. We chose toluene and aqueous solutions because a large portion of the wastes included in the Tank Risk Analysis Model are either aqueous or are comprised of mixtures of toluene and other organic solvents with similar viscosities and densities. The viscosities and densities of these two waste streams are shown in Exhibit 2-10.

For each model underground, in-ground and ongrade tank, the HWTF Model simulated two sets of 250 representative release profiles, one set representative of tanks handling aqueous waste streams and the other set representative of toluene.[8] Each waste stream modeled in the Tank Risk Analysis Model was classified as being more similar to either the generic aqueous or toluene waste stream. Thus, the risk estimates for a particular waste stream are based on representative release profiles for either the aqueous or toluene waste stream.

2.6 EVENTS THAT LEAD TO THE RELEASE OF CONTAMINANTS

After identifying the classes of tank systems and the release prevention and detection technologies to model, we then identified the various possible failure events. As a preliminary step in this process, we reviewed the relevant technical literature for information on system and component reliabilities and failure modes. This review focused on the causes, consequences, and probabilities of tank system failures.

Our literature search used the following sources and data bases:

- Pope-Reid Associates' (PRA) in-house library;
- University of Minnesota libraries;
- Computerized Engineering Index (a data base containing engineering abstracts);

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[7] Ideally, we would have run the HWTF Model for each of the 32 waste streams we have selected for this study.

[8] Because we modeled all waste streams associated with the distillation treatment process to be similar to toluene, only one set of HWTF results were generated for the on cradles distillation treatment tank. Similarly, we modeled all waste streams associated with the oxidation/reduction/precipitation process to be similar to the aqueous waste stream. Consequently, only one set of HWTF Model results were generated for each treatment tank technology.

EXHIBIT 2-10

GENERIC WASTE STREAM PROPERTIES USED FOR LEAK RATE CALCULATIONS

Generic Waste	Density a/ (kg/m^3)	Dynamic Viscosity a/ (centipoise)
Aqueous	998.21	1.00
Toluene	866.90	0.59

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a/ At 20°C.

- National Technical Information Service (computer search); and
- Pollution Abstracts (computer search).

From this literature search, we identified five general categories of failure mechanisms:

(1) Stresses due to unusual variations in the internal environment of the tank;

(2) Stresses due to the external environment of the tank;

(3) Design flaws;

(4) Construction and installation errors; and

(5) Operation or maintenance errors.

The possible effects of various internal environmental stresses are tabulated in Exhibit 2-11. This exhibit indicates that internal environmental factors contributing to failure include extremes of temperature, pressure, and pH, as well as variations in suspended solids, fluid viscosity, or specific gravity. Such internal stresses may result in accelerated corrosion, equipment overload, or failure of control or monitoring components. The affected components include tanks, pipes, pumps, valves, meters, and other ancillary equipment. Each type of internal stress, however, does not affect all components. For example, while pH extremes do affect all of the listed components, specific gravity variations only affect pumps, mixers, and flow meters.

External environmental stresses are tabulated in Exhibit 2-12. They include power fluctuations, exterior temperature extremes, high winds, humidity extremes, excessive rainfall, adverse soil conditions, earthquakes, poor air quality, and vandalism. These stresses may result in corrosion, rupture, spills, or control failure. The specific components affected by each type of stress are identified in the table.

Types of design, construction, and operation errors are tabulated in Exhibit 2-13. Such errors include poor material selection, use of improper components, inadequate structural support, improper process design, installation damage, use of off-spec materials or components, operator error, or improper maintenance. These errors may cause structural collapse, rupture, accelerated corrosion, equipment malfunction, inadequate capacity, improper process control, or failure to detect on-going releases. The specific components vulnerable to each of these failures are identified in the table.

Our findings indicate that the releases from tanks are due to a wide range of events. Because we do not know with certainty the sequence and consequence (i.e., magnitude of releases) of failure events that will occur at hazardous waste tanks, we used the HWTF model to simulate the sequence of events at

EXHIBIT 2-11

TANK SYSTEM FAILURE MATRIX: INTERNAL ENVIRONMENTAL STRESSES

		AFFECTED COMPONENTS												
Factors Contributing To Failure	Type of Failure	Above-Ground Tanks	In-Ground Tanks	Under Ground Tanks	Pumps	Valves	Above-Ground Piping	Under Ground Piping	Mixers	Heat Exchangers	Temperature Gauges	pH Meters, ORP Meters, & Conductivity Meters	Level Indicators	Flow Meter
Temperature extremes	Corrosion; inaccurate system control	*	*	*	*	*	*	*	*	*	*	*	*	*
Pressure extremes	Rupture or collapse; inaccurate system control	*	*	*	*	*	*	*		*				*
pH extremes	Corrosion; inaccurate system control	*	*	*	*	*	*	*	*	*	*	*	*	*
Excess amounts of solids	Abrasion; corrosion; inaccurate system control	*	*	*	*	*	*	*	*	*	*	*	*	*
Viscosity variations	Equipment overload; inaccurate system control				*	*			*	*	*			*
Specific gravity	Equipment overload; inaccurate system control				*				*					*

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* Signifies an effect upon the particular component or upon its operation.

Source: Based on literature search.

EXHIBIT 2-12

TANK SYSTEM FAILURE MATRIX: EXTERNAL ENVIRONMENTAL STRESSES

		AFFECTED COMPONENTS												
Factors Contributing To Failure	Type of Failure	Above-Ground Tanks	In-Ground Tanks	Under Ground Tanks	Pumps	Valves	Above-Ground Piping	Under Ground Piping	Mixers	Heat Exchangers	Temperature Gauges	pH Meters, ORP Meters, & Conductivity Meters	Level Indicators	Flow Meter
Inconsistent power	Overflow; variation or loss of control				*	*			*		*	*	*	*
Temperature	Cracking; corrosion; inaccurate system control	*	*	*	*	*	*		*	*	*	*	*	*
High winds/storms	Rupture; spills; overturning	*	*		*	*	*		*	*	*	*	*	*
Humidity extremes	Corrosion, inaccurate system control	*	*		*	*	*		*	*	*	*	*	
Excess rainfall	Overflow; short circuits; inaccurate/loss of system control; overturning	*	*	*	*	*	*	*	*	*	*	*	*	*
Adverse soil characteristics	Corrosion		*	*				*					*	*
Earthquakes	Rupture; overturning; spills	*	*	*	*	*	*	*	*	*	*	*	*	*
Adverse air quality	Corrosion	*	*		*	*	*		*	*				
Vandalism/ unauthorized entry	Rupture; overflow ignition; inaccurate/loss of system control	*	*	*	*	*	*	*	*	*	*	*	*	*
Other catastrophic event	Complete system failure	*	*	*	*	*	*	*	*	*	*	*	*	*

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* Signifies an effect upon the particular component or upon its operation.

Source: Based on literature search.

EXHIBIT 2-13

TANK SYSTEM FAILURE MATRIX: DESIGN, CONSTRUCTION, AND OPERATION ERRORS

		AFFECTED COMPONENTS												
Factors Contributing To Failure	Type of Failure	Above-Ground Tanks	In-Ground Tanks	Under Ground Tanks	Pumps	Valves	Above-Ground Piping	Under Ground Piping	Mixers	Heat Exchangers	Temperature Gauges	pH Meters, ORP Meters, & Conductivity Meters	Level Indicators	Flow Meter
DESIGN														
Poor material selection	Collapse or rupture; corrosion	●	●	●	●	●	●	●	●	●	●	●	●	●
Poor component selection	Undersized; inappropriate or inadequate				●	●			●	●	●	●	●	●
Inadequate structural specification	Non-support; structural weakness	●	●	●	●		●	●	●	●				
Inadequate process design	No or inadequate treatment of waste				●				●	●	●	●	●	●
CONSTRUCTION/INSTALLATION														
Damage during installation	Cracks, scrapes, dents, etc.	●	●	●	●	●	●	●	●	●	●	●	●	●
Off-spec materials installed	Corrosion; rupture or collapse	●	●	●	●	●	●	●	●	●	●	●	●	●
Off-spec component installed	Undersized; inadequate or malfunctioning				●	●			●	●	●	●	●	●
Expected service life	Equipment malfunction/failure	●	●	●	●	●	●	●	●	●	●	●	●	●
OPERATION/MAINTENANCE														
Operator fails to control process	Overflow; internal environmental extremes; failure to detect on-going release	●	●	●	●	●	●	●	●	●	●	●	●	●
Operator deliberately ignores safety or control measures	Overflow; internal environmental extremes; failure to detect on-going release	●	●	●	●				●	●				
Improper cleaning, inspection, observation, recordkeeing or replacement	Equipment malfunction/failure; failure to detect on-going release	●	●	●	●	●	●	●	●	●	●	●	●	●

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tanks. The HWTF model accounts for such random elements by simulating the timing and magnitude of failure events. For each type of failure, we have assigned probability distributions to those parameters which are subject to random variation (e.g., initial diameter of a corrosion hole or length and width of a rupture). These parameters are then used to determine the timing of the failure events and the magnitude of the releases resulting from the failure event. In general, the magnitudes of release volumes are determined by simulating relevant parameters (such as hole size) and using these parameters as input to a deterministic, mathematical leak rate equation.

In the following sections, we provide a general overview of the assumptions we used to simulate the timing and magnitude of release volumes for the major failure events (corrosion, ruptures, catastrophic events, overflows, and spills). In the last section, we describe the methods we used to model steady state losses from concrete tanks.[9] More detailed discussions of the distributions we used to simulate the failure events are provided in a separate report.[10]

2.6.1 Catastrophic Events

Catastrophic events may result from airplane crashes, high winds (tornadoes or hurricanes), earthquakes, floods, ignition of the waste, or damage from nearby fires or explosions. However, not all of these events are possible for any given system design; non-flammable wastes cannot burn, underground tanks are less susceptible to damage by explosions, and not all geographic regions are vulnerable to all of the other hazards. Thus, these events are controlled by the choice of waste streams and a set of geographic variables.

For this study, we modeled four types of catastrophic events: tornadoes, vandalism, nearby fires or explosions, and ignition of the waste within the tank (for toluene only, which is ignitable). Of course, not all of these events are possible for all system designs. For above-ground and inground tanks, we modeled all four of these events; however, for underground tanks, tornadoes and vandalism were disregarded, since the soil cover acts as a protective shield. In addition, we assumed that catastrophic damage to underground tanks due to nearby fires or explosions is only one-third as probable as for above-ground and in-ground tanks. This reduced probability is because of the protection provided by the soil cover. Information on catastrophic events is summarized in Exhibit 2-14.

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[9] We assumed that all concrete tanks are porous. Consequently, steady state losses occur from concrete tanks throughout the tank's operating life.

[10] Pope-Reid Associates, Inc., Hazardous Waste Tank Failure Model: Description of Methodology, draft report to Office of Solid Waste, EPA, January 13, 1986.

EXHIBIT 2-14

CATASTROPHIC EVENTS MODELED FOR DIFFERENT TANK TYPES

Event	Above-ground Tanks	In-ground Tanks	Underground Tanks
Tornado	X	X	
Vandalism	X	X	
Nearby fire or explosion	X	X	X a/
Ignition of the waste (toluene only)	X	X	X

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a/ We assumed that the annual probability of nearby fire or explosion for underground tanks is one-third of the annual probability for above-ground and in-ground tanks.

We assumed that these types of events cause the sudden loss of 50 percent of the volume of storage, accumulation, and SQG tanks, and 80 percent of the volume of treatment tanks. For storage, accumulation and SQG tanks, we assumed that on average, over a full year period, these tanks operate at half capacity. We assumed a higher loss for treatment tanks because they are usually operated near to their full capacities.

2.6.2 Corrosion of System Components

Corrosion of tanks and pipes involves two basic types of corrosion: localized corrosion and generalized corrosion. Either of these types of corrosion can occur on the interior and exterior surfaces of a tank or pipe. The model accounts for each corrosion mechanism (i.e., interior localized corrosion, exterior localized corrosion, interior generalized corrosion, exterior generalized corrosion) by calculating the time to occurrence of a hole based on a simulated corrosion rate and the assumed tank or pipe wall thickness. For example, if a localized exterior corrosion pit is simulated to grow in depth at a rate of 25 mils per year and the wall thickness is .25 inches, after 10 years the pit will perforate the wall. As corrosion progresses, the hole enlarges and the leak rate increases until the loss is detected and the component is replaced. In many cases, however, several corrosion mechanisms act at once, resulting in a hole in the tank or pipe wall much sooner than from any corrosion mechanism acting alone. For instance, generalized interior and generalized exterior corrosion may simultaneously reduce the wall thickness while a localized exterior corrosion pit enlarges. In this case, corrosion rates could be combined, resulting in a much faster corrosion rate.

Release volumes from corrosion holes in pipes and tanks are estimated by using one of two equations, depending on whether the corrosion holes are located in above-ground or underground components.[11] Above-ground leak rates are dependent on the following factors: the area of the crack or hole, the acceleration due to gravity, and the equivalent static hydraulic head (i.e., the equivalent height of the fluid surface above the hole, taking into account pressure additions due to pumps or losses due to fluid flow through pipes). The leak rate for underground tanks is different from that for above-ground tanks because the soil will impede the flow of fluid, dramatically reducing the leak rate. Thus we modeled the leaks from underground tanks to be dependent on the following factors: size of the hole, porosity, density of the released fluid, sphericity of the soil particles, average diameter of the soil particles; the pressure drop between the inside of the hole and the surrounding soil; and the distance required for leaking fluid to disperse. The total release volume for a given leak incident is calculated as the product of the leak rate and the duration of the leak. The latter varies according to the simulated effectiveness of modeled detection and monitoring options.

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[11] For a more detailed explanation of these equations see, Pope-Reid Associates, Inc., Hazardous Waste Tank Failure Model: Description of Methodology, draft report submitted to Office of Solid Waste, EPA, January 13, 1986, pp. 161-165.

2.6.3 Ruptures of Tank Components

Ruptures may result from one or two sources: undetected installation damage, including latent defects; and normal operating hazards. Normal operating hazards may produce ruptures at any time during the life of the tank system; these hazards include strains caused by settling, vibration, temperature variations, and vehicle collision. Undetected installation defects will result in immediate failures (i.e., the tank or pipe is installed in a ruptured condition that is not detected by a visual inspection).

We have assumed that steel and stainless steel are equally likely to rupture; stainless steel is not significantly stronger than ordinary carbon steel. Based on discussions with contractors, however, we have concluded that fiberglass is approximately twice as likely to rupture as is steel. We have therefore applied this ratio to our rupture and installation damage probabilities for both tanks and pipes.

Rupture mechanisms are different for above-ground and underground systems. Above-ground ruptures are most likely to occur due to vehicle collisions, collisions with fork lifts, freeze/thaw cycles, or latent flaws in design, fabrication, or installation. Below-ground ruptures are most likely to result from settling, latent defects, or the driving of heavy equipment across the site. These rupture mechanisms are different, but we have assumed that their combined probabilities are approximately equal for above-ground and underground systems.

In addition, we have assumed that rupture probabilities are independent of tank capacity and pipe length. We made this assumption because components are designed to accommodate the normal range of operating stresses. Thus, design strengths should increase with tank capacity and pipe length. We assumed that the increased design strength for larger components cancels out the increased stresses to which they are subject, so that rupture probabilities are independent of system design.

For double-walled tank system components, we modeled the inner and the outer walls separately, but we assumed that there is a 50 percent probability that a breach of the outer wall will also breach the inner wall. Because the inner wall is subject to fewer stresses than the outer wall, we assumed that a rupture is less likely to begin with the inner wall than with the outer wall. In addition, because operating pressures in hazardous waste tanks are generally low, we assume that only an insignificant fraction of ruptures initiating with the inner wall also breach the outer wall.

Ruptures include both large cracks and small seam failures. The corresponding release volumes associated with these types of failures are computed in the same manner as for corrosion holes, except the hole size does not increase with time. Since ruptures are often associated with larger hole sizes then those due to corrosion, higher leak rates are estimated for these failures. Consequently, we include a mass balance check to insure that the loss from a given rupture (or concurrent ruptures) does not exceed the capacity of the tank system (or throughput).

2.6.4 Overflows

Four conditions must be met before an overflow can occur:

- The tank must be almost full to capacity such that an overflow is possible;
- There must be a control error resulting in an attempt to add too much fluid to the tank;
- There must be a failure of the emergency shut-down system; and
- There must be a route by which overflowing fluid may escape from the tank (e.g. open top, vent).[12]

Clearly, a tank must first be full enough for an overflow to be possible; a half-empty 10,000 gallon tank, for example, cannot overflow by adding a 1,000-gallon batch. In general, we have assumed that potential overflow situations occur at any time for continuous treatment processes, because fluid is regularly added when the tank is already filled to its normal operating depth. We assumed that overflows are possible once per batch for batch treatment (distillation) processes because the operator is adding fluid from a storage tank which we assume to have larger capacity than the treatment tank itself. We assumed that overflows have the potential to occur only once per year for storage tanks, because storage tanks are generally filled in comparatively small batches and pumped-out before they get dangerously full. We made the conservative assumption that once per year there is a fluctuation in waste-generation rates or a failure to follow the pump-out schedule, thereby allowing the tank to become full.

Once a potential overflow situation develops, there must also be a control error before a tank can overflow. Such an error would occur if a malfunction in a level indicator caused too much fluid to be added to the tank (either in automatic or manual systems), if an automatic level controller failed, if the operator of a continuous system made an error in the morning start-up routine, or if the operator of a manual system ignored the liquid level indicator and added too much fluid.

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[12] If no route is available, the overflowing fluid backs up in the piping system.

However, even if a control error occurs, an overflow will not occur unless the emergency shut-down system fails. (See Section 2.3.2 for a description of the modeling of emergency shut-down systems.) The final requirement for an overflow to occur is that there be a route by which the excess fluid may escape. Open-topped tanks, for example, need no other overflow route, and pump-fed tanks can overflow through their vents.[13] Closed, gravity-feed tanks, however, are less subject to overflow, for the model assumes that their vent pipes open at a level above the highest possible fluid level in their fill tanks.[14] For such tanks, overflow can only occur through corrosion holes or ruptures in the fill pipe, the vent pipe, the outlet pipe or valve, or through faulty flanges or gaskets.

When an overflow occurs, the overflow rate is equal to the fill rate. For above-ground and inground tanks, the model estimates a detection time randomly selected from a uniform distribution with a lower bound of zero and an upper bound equal to the fill time. For underground tanks, if there is not a vent failure, the fluid simply backs up in the fill pipe and the tank does not overflow. If the vent does fail, the volume of the overflow is assumed to be 3.3 gallons, which is the model tank system's volume the vent pipe will contain.

2.6.5 Spills

Spills occur during filling and discharging and result when the operator fails to close a pump or strainer drain after maintenance, or when a portable flexible hose ruptures or is improperly connected. Which of these spill mechanisms is possible depends on the details of the system design. Treatment systems, for example, do not use portable hoses for fluid transfer, nor do they use strainers. Their pumps, however, are maintained annually, and there is a chance that the operator will forget to close a pump drain. This type of maintenance error will produce a spill the next time the pump is used. Storage, accumulation, SQG tanks, however, are pumped out using a flexible hose. Spills are possible if the hose ruptures or is improperly attached. On-site pumps and strainers were not modeled for storage, accumulation, or SQG tanks, because these pieces of equipment (if they are present) are generally located at the upstream end of the fill pipe of the tank, and are more closely associated with the operator's process equipment than they are with the storage or accumulation tank.

For spills resulting from failure to close the pump drain, the volume is estimated as the product of the discharge rate and a random detection time sampled from a uniform distribution with a lower bound of one minute and an upper bound of three minutes. For spills resulting from hose ruptures or loose connections, the leak rate is sampled from a uniform distribution with a lower bound of zero and an upper bound of the discharge rate. If the rate is greater than 0.375 gallons per minute, the detection time is randomly sampled from a uniform distribution with a lower bound of one minute and an upper bound equal to 25 percent of the discharge time. If the rate is between 0.002 and 0.375 gallons per minute, the detection time is randomly sampled from a uniform distribution with a lower bound of one minute and an upper bound equal to the discharge time. If the rate is less than 0.002 gallons per minute, the failure is undetected and the rupture leaks for the entire discharge time. The two rate levels (0.375 and 0.002) were determined using engineering judgment.

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[13] All oxidation/reduction/precipitation treatment tanks and in-ground tanks are assumed to be open-topped tanks.

[14] All underground tanks are closed, gravity-feed tanks.

2.6.6 Steady State Losses from Concrete Tanks

We have assumed that concrete tanks are porous and will, therefore, gradually release waste to the environment throughout their operating life. The steady state leakage rate is given by:

$$Q = A(1 + d/t)K \frac{(\alpha_{H_2O})}{\alpha_{waste}} \frac{(\rho_{waste})}{\rho_{H_2O}}$$

where:

Q = the rate of leakage

A = the surface area of the tank (sides and bottom only)

d = the average fluid depth in the tank

t = the thickness of the concrete (8 inches)

K = the permeability of the concrete to water (2.5×10^{-9} cm/sec)

α_{H_2O} = the viscosity of water

α_{waste} = the viscosity of waste

ρ_{waste} = the density of the waste

ρ_{H_2O} = the density of water

Using this equation, we find that a 10,000 gallon unlined concrete tank with an average aqueous fluid depth of nine feet will have a leak rate of 5.2 gallons/year. This leak rate will continue throughout the operating life of the tank.

In this chapter, we have presented the type of phenomena that the HWTF model simulates. Using assumptions about the timing of events, the model simulates 250 potential release profiles (i.e., the annual release of contaminants from the tank) associated with a particular tank technology and regulatory scenario. We used the model to simulate approximately 73 sets of potential release profiles.[15] From each set of 250 potential release profiles, a subset was selected to be used to calculate the human health risk estimates.[16] The next chapter presents how we used this subset of release profiles to estimate human health risks.

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[15] All of the 22 model technologies are not applicable to each of the regulatory scenarios. For example, concrete tanks are not analyzed to evaluate the corrosion protection scenario.

[16] Because using all 250 release profiles to generate risk estimates for each tank, ground-water setting, and regulatory scenario is a computationally intensive task, we did not have the Tank Risk Analysis Model generate a risk estimate for each of the 250 release profiles. See Section 4.5 for a description of the methodology we used to determine a subset.

CHAPTER 3

TRANSPORT, EXPOSURE, AND RISK MODELS

In this chapter, we discuss the component models of TRAM that are used to estimate the subsurface transport of contaminants released from hazardous waste tanks, human exposure to these contaminants via ingestion of contaminated ground water, and individual human health risks resulting from these exposures. The exposure pathway in this analysis consists of three major components:

- Transport of contaminants through the unsaturated zone;
- Transport of contaminants through the saturated zone; and
- Human exposure via consumption of contaminated ground water.

Simulation of this exposure pathway through the use of component models within TRAM allows individual exposures to contaminants released from tanks to be calculated, which in turn allows lifetime chronic non-carcinogenic and carcinogenic risks to be estimated for the exposed individual. The transport, exposure, and risk models contained in TRAM have been adapted for the purpose of this analysis from EPA's Liner Location Risk and Cost Analysis Model[1] (a model that compares risks and costs associated with various land disposal options for hazardous wastes). TRAM, like the Liner Location Model, is a non-steady-state model that allows yearly, time-varient exposures and risks to be estimated.

In this chapter, we describe our adaptation of these models to TRAM, and discuss their use within the overall framework of the analysis. Section 3.1 describes the unsaturated zone transport model used in TRAM, while Section 3.2 outlines the model used to simulate transport of contaminants in the saturated zone. Section 3.3 describes the exposure/risk model used in the analysis.

3.1 CONTAMINANT TRANSPORT IN THE UNSATURATED ZONE

In TRAM, contaminant transport in the unsaturated zone is estimated using the McWhorter-Nelson Wetting Front Model. This model represents contaminant transport by the movement of a wetting front generated by the release of liquid from the tank system. A wetting front is defined as the transition zone between soil layers with different water contents. The travel time for the wetting front is related to the difference in water content in the layers above and below the wetting front, the distance travelled in the unsaturated zone, the leakage rate (Darcian flux), and the retardation of contaminant flow by soil adsorption. The model is analytical (i.e., has a unique solution) and travel time is estimated using the following equation:

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[1] Liner Location Risk and Cost Analysis Model, draft report to the Office of Solid Waste, EPA, January 1985.

$$t = (L/q)\ (n - \theta_r)(q/k)^{x/(2 + 3x)} \qquad (3\text{-}1)$$

where:

t = travel time from bottom of tank to water table

L = distance traveled by wetting front (i.e., distance between tank and water table)

q = leakage rate through tank (length/time)

n = soil porosity (dimensionless)

θ_r = water content below wetting front (dimensionless)

K = hydraulic conductivity (length/time)

x = pore-size distribution index (dimensionless)

Contaminant transport in the unsaturated zone, as modeled by the McWhorter-Nelson model, is dependent not only upon properties of the aquifer but also upon source-specific information (i.e., amount of material released and physical/chemical properties of the released contaminants). In TRAM, we account for the effects of soil parameters by assuming that all tanks are located over a generic unsaturated zone that is assumed to be homogeneous and isotropic. Soil properties that affect flow (porosity, permeability, and pore-size distribution) are constant throughout the unsaturated zone. The generic unsaturated zone is assumed to be five meters in thickness, and soil moisture below the wetting front is considered to be constant. Also, we assume that the fractional organic carbon content (Foc) of the unsaturated zone remains constant throughout. Values for all of the unsaturated zone parameters used in the model are presented in Exhibit 3-1.

Liquid volume flux in the model is equated to the average annual volume of waste released from the tank (i.e., the total volume released divided by 20 years). This average liquid flux rate is somewhat of an over-simplification since in reality liquid release volumes will vary from year to year, and thus will affect unsaturated zone travel times. However, the model, as used within TRAM, is unable to account for year-by-year "pulses" of released liquid. In addition, this averaging has little effect on the overall risk estimate.

Although hazardous waste tanks may contain organic constituents that may volatilize during transport through the unsaturated zone, we do not consider this phenomenon in our analysis. For waste constituents with high vapor pressures, volatilization may be an important process that would result in

EXHIBIT 3-1

PHYSICAL/CHEMICAL PARAMETERS FOR GENERIC UNSATURATED ZONE a/

Parameter	Model Value
Depth (m)	5
Porosity (dimensionless)	0.25
Hydraulic Conductivity (m/yr) b/	5×10^{-3}
Pore-size Distribution Index (dimensionless)	3.5
Fractional Organic Carbon Content (dimensionless)	0.02
Bulk Mass Density (g/cm^3)	2.0
Soil Moisture (dimensionless) c/	0.1

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a/ Unsaturated zone is assumed to be homogeneous, isotropic sand.

b/ Saturated hydraulic conductivity.

c/ Soil moisture below wetting front.

lower mass loadings to the saturated zone; however, volatilization is difficult to predict quantitatively as it depends on many site-specific parameters. Our assumption that no volatilization takes place is therefore conservative and results in maximum contaminant loadings to the saturated zone.

Contaminant retardation and degradation within the unsaturated zone are predicted on a chemical-specific basis. Retardation is dependent on properties of the contaminant (e.g., hydrophobicity, polarity) and of the unsaturated zone (e.g., organic carbon content, porosity, bulk density), and is calculated for each contaminant using the following equation:

$$R_D = 1.0 + (p/n) * (Foc * Koc) \qquad (3\text{-}2)$$

where:

R_D = retardation factor (dimensionless)

p = bulk density of unsaturated zone materials (g/cm^3)

n = porosity of unsaturated zone materials (dimensionless)

Foc = fractional organic carbon content of aquifer (dimensionless)

Koc = organic carbon-water partition coefficient for contaminant (cm^3/g)

As seen in Exhibit 3-6, Koc values for the 120 chemicals found in the TRAM chemical data base vary widely, and, subsequently, retardation factors for these compounds vary from slightly greater than 1 to more than 10,000.

Contaminant degradation in the unsaturated zone may be the result of chemical or biological processes. In TRAM these two processes are modeled through the use of a single first-order decay function:

$$C = C_o * \exp[-k * t] \qquad (3\text{-}3)$$

where:

C = contaminant concentration in unsaturated zone after degradation has been taken into account (mg/L)

C_o = contaminant concentration in unsaturated zone before degradation has been taken into account (mg/L)

k = first-order reaction rate constant (years^{-1})

t = travel time in unsaturated zone (years)

Thus, all relevant chemical and biological processes (e.g., chemical hydrolysis, aerobic degradation) are lumped together into the first-order rate constant, k. In reality, chemical and biological reaction rates are very site-specific and depend on parameters such as temperature and availability of oxygen. However, we are unable to account for these site-specific dependencies in our analysis, and therefore use specified rate constants (derived from a number of literature estimates) in all situations. Information on degradation in the subsurface environment, however, is not available for many hazardous chemicals; we assume that chemicals for which data are unavailable are infinitely persistent.

In addition to the model assumptions noted above, we also assume that no interactions between contaminants occur in the unsaturated zone (contaminant interactions could decrease travel time due to the mobilization of hydrophobic organics by water-miscible organic solvents or an immiscible solvent phase). Also, all adsorption reactions are considered to be fast and reversible, and adsorption is considered to be linear over the range of contaminant concentrations seen in the analysis. Finally, we assume that no dispersion in any direction occurs during transport through the unsaturated zone.

Although these assumptions tend to oversimplify transport and attenuation processes occurring in the unsaturated zone, they are consistent across all situations and thus allow the model to be used for direct risk comparisons. Final model output is a mass loading for each contaminant to the saturated zone transport model, which is described below.

3.2 CONTAMINANT TRANSPORT IN THE SATURATED ZONE

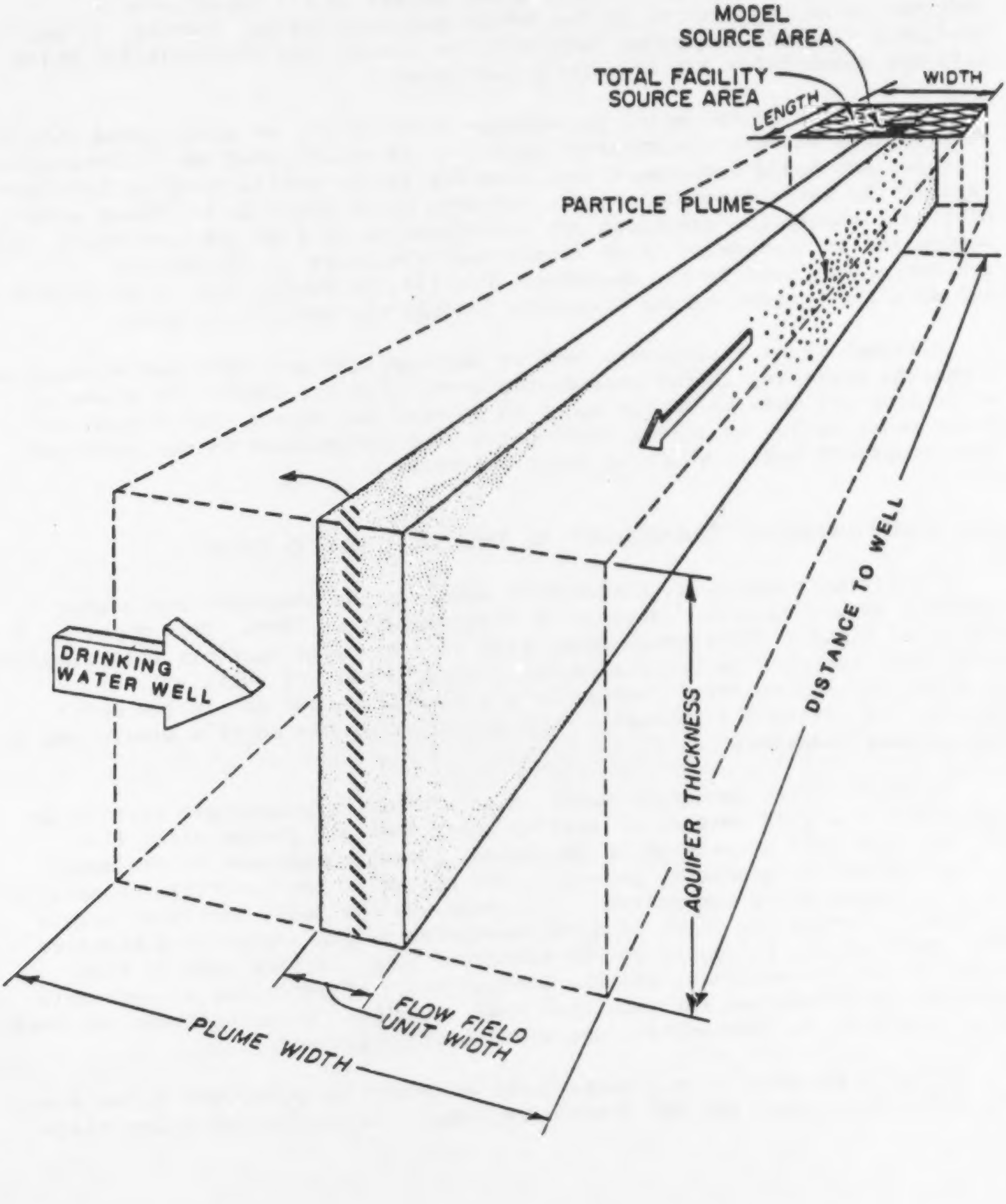
The Prickett-Lonnquist Random Walk model is the component model used to estimate saturated zone transport of contaminants in TRAM. This model is a numerical (finite difference) model with variable grid spacings that simulates advective transport in two dimensions (longitudinal and vertical). Longitudinal and vertical dispersion are also accounted for in the model. Exhibit 3-2 presents a schematic representation of the model's simulation of contaminant transport.

In the Prickett-Lonnquist model, a particular hydrogeologic setting is divided into a grid network of smaller subregions and ground-water flow through this grid or network is estimated. Input parameters to the model include hydraulic gradient, porosity, and hydraulic conductivity for each of the flow units being considered. Additionally, the model simulates solute transport through the input of 1,000 particles (which represent a standard mass input of one kilogram) to the saturated zone. A time step is then selected for the analysis, and the concentration of particles at each grid boundary is calculated for each time step. Particle concentrations are used as a surrogate for contaminant concentrations in the model.

Particle movement (i.e., contaminant movement) is simulated in two steps; the advective stage, and the dispersive stage. During the advective stage,

Exhibit 3-2

Simulation of Contaminant Transport in the Saturated Zone by the Prickett-Lonnquist Random Walk Model


MODEL SOURCE AREA
TOTAL FACILITY SOURCE AREA
LENGTH
WIDTH
PARTICLE PLUME
DRINKING WATER WELL
DISTANCE TO WELL
AQUIFER THICKNESS
FLOW FIELD UNIT WIDTH
PLUME WIDTH

the distance the particle has traveled due to advective flow is calculated (this distance is equal to the ground-water velocity multiplied by the time step). In the dispersive stage, the distance a particle travels is equal to a random number selected from a distribution multiplied by a longitudinal or vertical dispersion coefficient (the final value calculated for dispersive stage movement may be positive or negative). The actual distance traveled by a particle during a time step is then calculated by summing the distance calculated for the advective and dispersive stages. This process is repeated for each particle for each time step for which the model is run.

Particles entering each downgradient grid are counted and converted to a mass flux, with the average concentration for that grid taken to be the ratio of the mass flux of particles and the volumetric flux of water (i.e., the number of particles divided by the volume of liquid contained within the grid region). Grid volume is multiplied by soil porosity to obtain the percentage of each grid volume occupied by water.

Thus, by calculating volumetric and mass fluxes for the grid containing a drinking water well, concentrations of contaminants at the well can be estimated. It should be noted that the following assumptions apply in estimating well concentration:

- Dilution and drawdown effects from well pumping are not evaluated;
- Wells are located directly downgradient from the source of contamination;
- Drinking water wells draw only from the contaminated aquifer(s) of interest, and draw water from the full thickness of the aquifer(s); and
- Transverse dispersion is not modeled within the Prickett-Lonnquist model.

For the purpose of this analysis, the first three assumptions were considered reasonable, because well pumping effects are very site-specific and could not be easily incorporated into such a broad-based analysis, and because they are consistent and conservative assumptions. However, transverse dispersion may be a very important process affecting the transport of contaminants in ground water, particularly for situations where the source of contamination closely approximates a true point source (e.g., a tank) . Thus, we modified Prickett-Lonnquist model predicted concentrations for transverse dispersion according to the following expression:

$$C_{adj.} = C_{unadj.} * (1/\pi * n * t * D_y)^{\frac{1}{2}} \qquad (3\text{-}4)$$

where:

$C_{adj.}$ = well concentration adjusted for transverse dispersion (mg/L)

$C_{unadj.}$ = unadjusted well concentration from Prickett-Lonnquist model (mg/L)

π = 3.14

n = porosity (dimensionless)

t = time of travel from source to well (years)

D_y = transverse dispersion coefficient (m^2/year)

The transverse dispersion coefficient is specific to the aquifer of interest, and is considered to be a function of distance from the source and aquifer velocity.

Contaminant degradation (both chemical and biological) within the saturated zone is accounted for in an identical manner to the unsaturated zone model. The same first-order rate constants for each contaminant are used to account for degradation in both the unsaturated and saturated zones, and thus differences in reaction rates or degradation processes between the two zones are not taken into account. However, there is sufficient uncertainty with respect to contaminant degradation to warrant this assumption, even though physical, chemical, and biological parameters between the two zones may vary significantly.

The saturated zone model of TRAM also considers contaminant retardation, but in a somewhat different fashion from the unsaturated zone model. Unique R_D values are calculated for all contaminants, based on Koc values and relevant aquifer parameters, and using equation 3-2 as presented in Section 3.1 of this chapter. However, rather than using these contaminant-specific values in the actual transport model, contaminants are grouped into four mobility classes based on R_D values, and the model is run using median R_D values for each of the four classes. Contaminant mobility classes and median R_D values are as follows:

Mobility Class	R_D Range	Median R_D
1	less than 10	1.3
2	10 to 100	32
3	100 to 10,000	360
4	greater than 10,000	160,000

These mobility classes were used because using chemical-specific R_D values would require a run of the Prickett-Lonnquist model to generate a standard breakthrough curve for each contaminant in each flow field. Performing all the necessary runs woul be a computationally intensive task. Consequently, we grouped the chemicals into the four mobility classes so that only four runs were needed for each generic hydrogeologic setting.

For these four mobility classes, the Prickett-Lonnquist model estimates well concentrations for a release of one kilogram (1000 particles) of the source. These results are then adjusted for contaminant degradation and transverse dispersion. However, the concentration profiles, or breakthrough curves, (Exhibit 3-3) generated by the model are for only one annual release of one kilogram. Therefore, for a source releasing for longer than a year, such as a tank, it is necessary to sum the yearly breakthrough curves to obtain the actual concentration profile for a particular contaminant at an exposure well. The methodology for summing individual breakthrough curves is illustrated graphically in Exhibit 3-4.[2]

TRAM does not actually incorporate the Prickett-Lonnquist program code, but rather references a set of "standard breakthrough curves" of Prickett-Lonnquist model results. The "standard breakthrough curve" for a particular mobility class and hydrogeologic setting contains Prickett-Lonnquist model results for each year in which a contaminant appears at an exposure well. By multiplying the "standard breakthrough curve" value for a particular year by the saturated zone mass loading for a contaminant, the well concentration for that containment in that year is calculated. Thus, these values are used to calculate yearly, time-varying concentrations of a particular contaminant at an exposure well for a given set of hydrogeologic and mass loading conditions, rather than peak or average concentrations. As described in Chapter 1, mass loading conditions are based on HWTF model release volumes for a particular tank, and annual disposal rates and concentrations of contaminants in a given waste stream.

Hydrogeologic conditions such as horizontal and vertical ground-water velocities and aquifer configurations and thicknesses are represented in TRAM by a set of nine generic flow fields developed for the Liner Location Risk and Cost Analysis model. Because of lack of data on actual hydrogeologic conditions at hazardous waste tank facilities, and because of the need to simplify the analysis relative to the potential variations in hydrogeology at real tank facilities, we selected these nine flow fields as being reasonably representative of conditions that would be most commonly encountered.

The nine flow fields encompass horizontal ground-water velocities of 1 to 10,000 m/year, and represent single and double layer aquifers with and without intervening nonaquifer layers. These generic flow fields were developed based on an extensive literature review of ground-water modeling studies and evaluations in the U.S., and are considered to be representative of the range of hydrogeologic conditions most commonly encountered at hazardous waste land disposal facilities (i.e., landfills and surface impoundments) throughout the country. Physical parameters (i.e., horizontal and vertical velocities, aquifer configurations, and porosity values) are summarized for the nine generic flow fields in Exhibit 3-5. Of the note is that all earth materials in all of the nine flow fields are assumed to be homogenous and isotropic.

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[2] In situations where the summed breakthrough curves exceed the solubility limit for a contaminant, the well concentration for that contaminant is limited to solubility (solubility values for TRAM contaminants are presented in Exhibit 3-6).

EXHIBIT 3-3
STANDARD BREAKTHROUGH CURVE FOR TRANSPORT MODEL
(SCENARIO A-1-60)

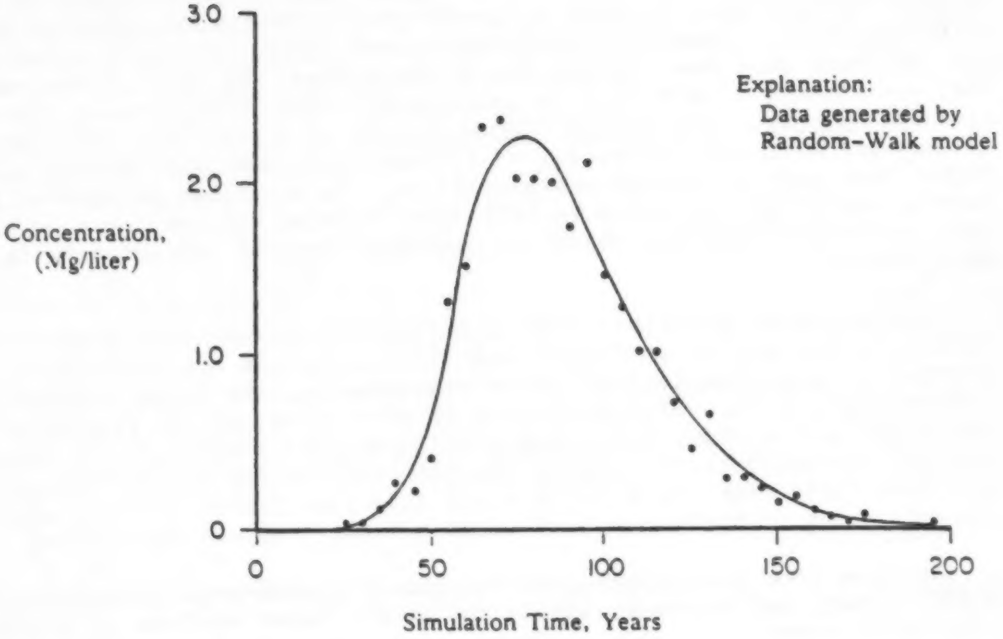
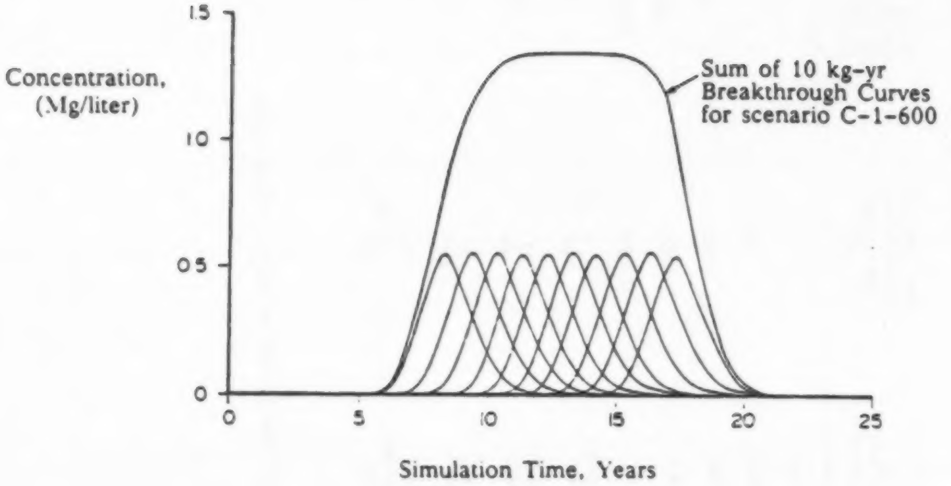


EXHIBIT 3-4
GRAPHICAL REPRESENTATION OF THE METHODS FOR SUMMING INDIVIDUAL BREAKTHROUGH CURVES TO OBTAIN THE CONCENTRATION PROFILE AT AN EXPOSURE WELL



Note: Individual 1 yr input curves have not been scaled to any particular facility size/unit mass load

EXHIBIT 3-5

HYDROGEOLOGICAL PARAMETERS FOR THE NINE GENERIC FLOW FIELDS IN TRAM

Flow Field	Layer	Aquifer/ Nonaquifer	Horizontal Ground-water Velocity (m/yr)	Vertical Ground-water Velocity (m/yr)	Porosity	Thickness (m)
A	upper	aquifer	1	0.1	0.30	30
B	upper	aquifer	10	1	0.20	30
C	upper	aquifer	100	10	0.20	30
D	upper	aquifer	1000	100	0.1	30
E	upper	aquifer	10,000	1000	0.01 a/	30
F	upper	nonquifer	0.05	0.5	0.45	15
	lower	aquifer	100	2	0.20	30
G	upper	aquifer	100	10	0.20	30
	lower	aquifer	10	0.1	0.20	60
H	upper	aquifer	10	1	0.20	15
	lower	aquifer	100	1	0.20	15
I	upper	aquifer	10	0.5	0.20	30
	middle	nonaquifer	0.05	0.5	0.45	30
	lower	aquifer	100	1	0.20	30

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a/ Assumed to represent homogeneously fractured or karstified rock.

For the Tank Risk Analysis Model, the Prickett-Lonnquist model was run for the nine generic flow fields, with assumed exposure well distances set at 60, 600, and 1500 meters, for the four modeled mobility classes.[3] Thus, the table of "standard breakthrough curves" within TRAM contains model results for 108 scenarios (nine flow fields x three exposure well distances x four mobility classes). Well concentrations are calculated by multiplying the selected breakthrough curve value for a particular year by the unsaturated model value for mass loading to the saturated zone, and then adjusting the predicted concentration for transverse dispersion and degradation.

The saturated zone transport values in TRAM are not suitable for site-specific analyses, as there is no way to directly incorporate site hydrogeologic conditions into the model. Moreover, developing and using the saturated zone model and generic flow fields require several simplifying assumptions that affected the model's results and limit its applicability. Some of these assumptions and limitations are as follows:

- Mobilities for a group of contaminants are assumed to be reasonably represented by a single median R_D value for the group. This use of a median value leads to significant under-estimation of transport times for contaminants with R_Ds slightly less than the cut-off values for the four mobility classes.

- Degradation occurs only for contaminants whose decay rates are readily available, and always at the specified first-order rate. Degradation rates may vary significantly from these assumed rates, and thus using a single value may under-estimate or over-estimate the effect of degradation on contaminant concentrations at exposure wells. Also, many organic chemicals decay at rates that are so slow that they are difficult to measure, but which could dramatically reduce concentrations over long time periods.

- The range of hydrogeologic conditions at tank facilities are assumed to be adequately represented by the nine generic flow fields selected for the analysis. These flow fields are representative of a wide range of ground-water velocities, but do not account for fractured aquifers, karst aquifers, and other heterogeneous, anisotropic hydrogeologic situations. These conditions could greatly affect tranport times and thus have an effect on human exposure to contaminant releases from tanks.

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[3] In order to compare the regulatory scenarios, we generated risk estimates only for exposure at the 60 meter well.

Despite these limitations, the saturated zone transport approach used in TRAM is considered useful for comparing the transport of contaminants in different hypothetical generic situations. In general, the model is conservative in its assumptions, and in most situations will tend to over-estimate well concentrations for contaminants. Assumptions are consistent across all flow fields and contaminants, and, therefore, the model provides the user with the ability to make direct comparisons between different hydrogeologic settings and contaminants of concern.

Results from the saturated zone transport model (i.e., contaminant concentrations at exposure points) are input to the exposure/risk component model of TRAM. The exposure/risk model is described in the next section.

3.3 EXPOSURE/RISK MODEL

The exposure/risk model converts ambient environmental concentrations of chemicals to estimates of human health risk. The exposure component calculates annual and lifetime chemical doses to exposed individuals over the modeling time period, based on several standard assumptions about intake. The risk component estimates lifetime individual risk of cancer and other toxic effects associated with chemical exposures. We estimate lifetime individual risk estimates for each year of our 400-year model time horizon. To summarize the lifetime individual risks for a particular chemical over the 400-year time horizon, we average the 400 lifetime individual risk estimates. The following sections describe how we calculated the lifetime individual risk for a given year.

3.3.1 Exposure Component

The exposure component of the model converts chemical concentrations in drinking water into chemical doses to exposed individuals. TRAM focuses on the toxic effects of chronic chemical exposures, and therefore is based on lifetime chemical dose.[a] As a result, the yearly chemical concentrations predicted by TRAM must be transformed to average lifetime dose levels, in mg/kg-day. These lifetime dose values are taken as inputs to the next step in the risk analysis sequence, risk estimation.

The starting point for dose estimation is a time profile of ground-water concentration at an exposure well. The value corresponding to each year represents the estimated drinking water concentration in that year (effects of water treatment are not included), which is converted to an annual dose by assuming that average human drinking water consumption is two liters per day, average human body weight is 70 kilograms, and absorption efficiency is 100 percent.

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[a] Exceptions to this are the few chemicals in the data base classified as teratogens or subchronic toxicants. Risks for these chemicals are based on yearly (smallest time increment in the model) doses.

The yearly dose profile is then transformed to a profile of 70-year-average doses, with 70 years the assumed human life span for all individuals over the entire modeling period. This transformation is done by averaging each yearly dose with the 69 immediately preceding yearly doses (i.e., calculating a 70-year moving average over the entire period). The dose is assumed to be zero for the 69 years preceding the start of the modeling period. Therefore, each value in the transformed profile represents the average dose that a hypothetical person reaching 70 years of age in that year would have been exposed to in their lifetime.[5] These moving average doses are appropriate values to use in lifetime risk calculations. Unaveraged yearly doses are inappropriate as they do not represent lifetime exposures. A single 400-year (or any other period) average concentration would greatly limit the type and accuracy of possible risk estimates.

The major advantages to using 70-year moving averages as a measure of exposure instead of individual yearly doses or single period averages are:

- Allows risk calculations for effects having non-linear dose-response functions (i.e., threshold effects, carcinogenic effects at high doses);
- Allows distribution of risks over time; and
- Allows calculation of risk magnitude and variance over time, and estimation of values such as maximum, median, and various percentile risks.

The 70-year moving average approach to exposure estimation more realistically reflects the toxicology of chronic exposures and more accurately represents the time element in the risk analysis.

3.3.2 Risk Component

Estimating potential human health effects entails predicting quantitatively the consequences of human exposure to disease-causing agents. Traditionally, toxicologists use two different approaches to characterize the potential health effects of chemical exposures. First, they commonly accept a non-threshold assumption for carcinogenic effects. EPA policymakers have followed their lead, using a linear, non-threshold dose-response model to calculate a unit risk value (risk per unit dose) for a chemical at low doses which, in turn, enables them to calculate explicit risks to individuals. Second, toxicologists generally assume that there is a threshold for noncarcinogenic effects. For these effects, a dose-response model has not generally been used to estimate human health risks. Rather, an experimentally determined effects threshold is divided by appropriate safety factors to estimate an allowable daily intake (ADI). The ADI is compared to projected exposure levels to provide an indication of the potential for noncarcinogenic health effects.

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[5] Note that the risks estimated based on these lifetime doses are assigned to the final year of the assumed life span (i.e., the end of the hypothetical exposed individual's life). Clearly, potential effects from predicted chronic exposures would actually be distributed within the time period between initial exposure and the end of the assumed life span. No attempt is made to more accurately assign chronic risks over an individual's lifetime because: (1) there is little precedent for this, and considerable research into latency and timing of effects for specific chemicals would be necessary to develop an approach, and (2) this level of detail is beyond the scope of the planned regulatory analysis for tanks.

The risk estimation component in TRAM diverges from the traditional approach for chemicals with noncarcinogenic effects because the binary nature of the traditional approach (i.e., the effect either does or does not occur at a given dose, as opposed to having a probability of occurrence) is not very useful for explicit risk analysis. We have incorporated a dose-response model that estimates risk from noncarcinogens as a continuous function of dose at dose levels above the threshold, enabling us to treat these risks in a fashion more amenable to regulatory analysis. In the following sections we describe the risk component of this model and summarize the methodology for developing the necessary dose-response parameters for specific chemicals. A set of toxicity profiles, available as a supplemental document to the Liner Location Risk and Cost Analysis Model (LLRCAM) report, documents the derivation of dose-response parameters for individual chemicals.

Carcinogenic Effects. The model estimates risk for potential carcinogens using the one-hit equation:

$$R = 1 - \exp(-H * D) \qquad (3\text{-}5)$$

where:

R = lifetime individual risk (i.e., probability of an individual developing cancer over a lifetime)

H = potency, or unit risk $(\text{mg/kg/day})^{-1}$

D = lifetime average dose (mg/kg/day)

This equation assumes no threshold (i.e., there is a finite risk for any dose level) and is linear at low doses, an approach consistent with EPA's proposed cancer risk assessment guidelines (49 Federal Register 46294-46301, November 17, 1984). The dose, D, used in this equation is developed within the tank model and is the ultimate output of the release and transport models. The potency, H, is chemical-specific and represents the response per unit dose of a chemical. Higher H values are indicative of more potent carcinogens, which produce higher risks than less potent chemicals at the same dose. For most potential carcinogens, H values are set equal to the upper-bound unit risk parameters (q_1*) calculated by EPA's Carcinogen Assessment Group (CAG) using the linearized multistage model and the most appropriate set of experimental data. Most of the unit risk parameters are based on animal studies. To use animal data to estimate human cancer risk, the risk to humans is assumed to be equal to the risk to animals at the same dose per unit surface area. This assumption is consistent with current EPA policy for carcinogenic risk assessment. For a few potential carcinogens that did not have a unit risk value develoepd by CAG, H values were estimated by applying the one-hit equations to an appropriate set of experimental data.[6] The studies these values are based on are documented in a set of toxicity profiles. These profiles are available as a supplemental document to the LLRCAM Report.

Noncarcinogenic Effects. The model uses the Weibull equation with a threshold, as shown below, to estimate risks of noncarcinogenic effects:

$$R = 1 - \exp\left[-H * (D-t)^{K}\right] \qquad (3\text{-}6)$$

where:

R = lifetime individual risk (i.e., probability of the effect being modeled occurring in an individual over a lifetime)

H = Weibull dose-response parameter $(\text{mg/kg/day})^{-K}$

D = lifetime average dose (mg/kg/day)

t = effect threshold (mg/kg/day)

K = Weibull shape parameter

This equation incorporates an effect threshold, below which risk equals zero. At doses above the threshold, risk is a funtion of dose and two chemical-specific parameters, H and K. The lifetime dose, D, for this equation is defined and calculated in an identical way to the dose for the carcinogenic risk equation. The threshold, t, is chemical-specific and is derived from the same experimental data used to develop H. The shape parameter, K, which theoretically could vary for different chemicals or different effects, is set to two for all noncarcinogenic effects. Assigning a value for K is an approximation, but is necessary because of the lack of sufficient dose-response data for noncarcinogenic effects to derive a unique value of K for many specific chemicals. The primary basis for assigning K equal to two is a statistical analysis of a limited number of data sets obtained from the primary literature.[7]

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[6] Only one potential carcinogen modeled in this study has an H value that is not based on a CAG unit risk. Low risk estimates are associated with this chemical, toluene diisocyanate, because it immediately hydrolyzes in water.

[7] This study was done by Science Research Systems, Inc. (now K.S. Crump and Co.). The complete study report is reproduced as an attachment to Appendix D of the Liner Location Risk and Cost Analysis Model report.

Thus, the key chemical-specific parameter defining the dose-response curve for noncarcinogenic effects is H. For each chemical, values for H were estimated from three toxicologic parameters extracted from an appropriate study: (1) the chronic minimum effective dose (MED); (2) the effect threshold (t); and (3) the response fraction at the MED (termed Ro). Both the MED and threshold were converted from animal values to human equivalent values based on relative surface area. For chemicals with multiple studies, the study reporting an adverse effect at the lowest dose was selected as the basis for H.

When chronic studies were unavailable, MED and threshold values from subchronic studies were divided by five to convert to equivalent chronic values. For many chemicals the effect threshold was not determined from the experimental data but was estimated by dividing the human equivalent chronic MED by a factor of 100 (10 to convert from chronic human equivalent MED to chronic human equivalent no-effect level, 10 to account for intraspecies variability). Many studies are reported with insufficient detail to allow estimation of Ro, and in these cases Ro was set to 10 percent for dichotomous (quantal) effects and 90 percent for continuous effects.[a]

After values for MED, t, and Ro are determined from an appropriate study or estimated as described above, calculation of H is relatively straightforward. Rearranging equation 2 and substituting K = 2, R = Ro, and D = MED gives the following calculation form for H:

$$H = \frac{-\ln(1 - Ro)}{(MED - t)^2} \qquad (3\text{-}7)$$

The toxicity studies used to derive H values are documented in individual toxicity profiles that are a supplement to the Liner Location Risk and Cost Analysis report. Values for H, MED, and t used in the tank risk analysis are listed in Exhibit 3-6.

3.3.3 Limitations of the Exposure/Risk Estimation Model

The primary limitations and assumptions in the exposure/risk estimation model include those traditionally associated with determining quantitative toxicity parameters and characterizing dose-response in low dose regions. Major assumptions are:

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[a] Dichotomous effects either occur or don't occur in each test subject, and the response frequency is simply the number with the effect as a fraction of the total. Continuous effects, such as organ weights or enzyme levels, are often reported as average values for the total test group without data on individual response. Continuous effects data were "converted" to dichotomous data by assuming that most (90 percent) of the test invididuals are affected at the MED.

- Considering human and animal toxic responses to be similar at similar doses on a surface area basis. Differences in size, lifespan, metabolism, and physiology between humans and test animals complicate the applicability of animal data to estimates of human risk. However, the scientific community generally accepts animal responses as a valid indicator of human responses.

- Using data from subchronic studies to infer chronic toxic effects. Because TRAM assesses human health risks due to chronic exposures, data from long-term studies are preferable. Often these data are not available, so we have extrapolated from subchronic studies. This extrapolation increases the uncertainty in the quantitative assessment of chronic potencies and also creates the possibility of ignoring an effect that occurs only after chronic exposures.

- Assuming that the dose-response for carcinogens is linear at low doses and that there is no threshold dose (i.e., using the one-hit model). This theoretical approach is widely accepted and often used by policymakers to provide a conservative estimate of carcinogenic risk.

- Assuming that response from exposure to noncarcinogens at low doses declines more rapidly with decreasing dose than a linear function would predict. Similarly, at high doses the response rises more rapidly than a linear model would predict.

- Assuming that all dose-response curves for non-carcinogens have the same Weibull shape parameter. This assumption may under- or over-estimate risk for some chemicals.

EXHIBIT 3-6

CONSTITUENTS REFERENCED BY TRAM a/

		PHYSICAL/CHEMICAL DATA			TOXICITY DATA				
CONSTITUENT	INORG/ ORG	SOLUBILITY (MG/L)	ATTEN AK (YR-1)	KOC	UNIT RISK H (MG/KG-DAY)-K	K	THRESHOLD (MG/KG-DAY)	EFFECT	DETECTABLE CONCENT (MG/L)
2 ACENAPHTHYLENE	1	0.3930E+01	0.0	0.2500E+04	0.1150E+02	1	0.0000E+00	CANCER	0.1E-01
3 ACETALDEHYDE	1	0.1000E+07	0.0	0.2190E+01	0.2500E-01	2	0.9700E-01	TRACHEA	0.0E+00
4 ACETONE	1	0.1000E+07	0.0	0.2190E+01	0.6600E-02	2	0.1900E+00	STOMACH	0.5E-02
5 ACETONITRILE	1	0.1000E+07	0.0	0.2190E+01	0.4900E+00	2	0.2200E-01	MULT ORG	0.0E+00
7 ACRYLONITRILE	1	0.7900E+05	0.0	0.8500E+00	0.2400E+00	1	0.0000E+00	CANCER	0.1E+00
8 ALDICARB	1	0.6000E+04	0.0	0.3650E+02	0.1040E+05	2	0.1500E-03	MORTALIT	0.0E+00
12 ARSENIC	0	0.1500E+05	0.0	0.5000E+01	0.1500E+02	1	0.0000E+00	CANCER	0.2E-01
14 BENZENE	1	0.1780E+04	0.0	0.8300E+02	0.2900E-01	1	0.0000E+00	CANCER	0.5E-02
22 CADMIUM	0	0.2000E+01	0.0	0.5000E+03	0.6600E+04	2	0.2900E-03	KIDNEY	0.2E-01
24 C.TETRACHLORIDE	1	0.7850E+03	0.0	0.4390E+03	0.1300E+00	1	0.0000E+00	CANCER	0.5E-02
28 CHLOROFORM	1	0.8200E+04	0.5	0.4400E+02	0.7000E-01	1	0.0000E+00	CANCER	0.5E-02
30 CHROMIUM	0	0.4400E+06	0.0	0.5000E+01	0.2400E+01	2	0.1000E-01	KID&LIV	0.2E-01
31 CHRYSENE	1	0.1800E-02	0.0	0.2000E+06	0.1150E+02	1	0.0000E+00	CANCER	0.2E-01
32 COPPER	0	0.1100E+06	0.0	0.5000E+04	0.3600E+01	2	0.4000E-01	BLOOD	0.2E-01
33 CYANIDES	0	0.3300E+06	0.1	0.5000E+01	0.3100E+00	2	0.8700E-02	THYROID	0.0E+00
36 12-DCBENZENE	1	0.1000E+03	0.0	0.1700E+04	0.3500E-01	2	0.8300E-01	KID&LIV	0.1E-01
41 DICHLOROMETHANE	1	0.2000E+05	0.4	0.8800E+01	0.6300E-03	1	0.0000E+00	CANCER	0.5E-02
51 24-DINITROTOLUENE	1	0.2700E+03	0.0	0.4500E+02	0.3100E+00	1	0.0000E+00	CANCER	0.2E-01
61 HCBENZENE	1	0.6000E-02	0.0	0.3900E+04	0.1670E+01	1	0.0000E+00	CANCER	0.1E-01
62 HCBUTADIENE	1	0.2000E+01	0.0	0.2900E+05	0.7750E-01	1	0.0000E+00	CANCER	0.1E-01
64 HCCYCLOPENTADIENE	1	0.2000E+01	23.0	0.4800E+04	0.6100E+09	2	0.6200E-06	BLOOD	0.1E-01
68 LEAD	0	0.1250E+03	0.0	0.5000E+04	0.6200E+05	2	0.1300E-02	BLOOD	0.2E-01
69 LINDANE	1	0.7800E+01	0.0	0.1100E+04	0.1330E+01	1	0.0000E+00	CANCER	0.5E-05
72 METHANOL	1	0.1000E+07	0.0	0.2190E+01	0.2820E+03	2	0.9200E-03	MULT ORG	0.0E+00
75 M.E.KETONE	1	0.3530E+06	0.0	0.3880E+01	0.5500E-05	2	0.2300E+01	EMBRYO	0.0E+00
82 NICKEL	0	0.8200E+02	0.0	0.5000E+03	0.1820E+02	2	0.7700E-03	REPROD	0.2E-01
89 PCPHENOL	1	0.1400E+02	0.0	0.5300E+06	0.6300E+01	2	0.6100E-02	EMBRYO	0.1E-01
90 PHENOL	1	0.9300E+05	0.0	0.6000E+01	0.1030E+01	2	0.1500E-01	KIDNEY	0.1E-01
98 TETRACHLOROETHENE	1	0.2000E+03	0.9	0.3640E+03	0.5100E-01	1	0.0000E+00	CANCER	0.5E-02
99 THALLIUM	0	0.2400E+06	0.0	0.5000E+03	0.3050E+03	2	0.2800E-03	WEIGHT	0.0E+00
100 TOLUENE	1	0.5350E+03	0.0	0.2500E+03	0.1800E+00	2	0.3600E-01	WEIGHT	0.5E-02
102 TDI	1	0.0000E+00	130000.0	0.1550E+01	0.4300E-02	1	0.0000E+00	CANCER	0.0E+00
105 111-TCETHANE	1	0.4400E+04	1.4	0.1520E+03	0.1600E-02	1	0.0000E+00	CANCER	0.5E-02
107 TCETHENE	1	0.1100E+04	0.7	0.1260E+03	0.1100E-01	1	0.0000E+00	CANCER	0.5E-02
112 XYLENE	1	0.1600E+03	0.0	0.2680E+03	0.1400E+00	2	0.4100E-01	LIVER	0.5E-02
117 CHLORIDE	0	0.2200E+06	0.0	0.5000E-01	0.7700E-05	2	0.1700E+02	HYPERTEN	0.0E+00

a/ The constituent data base actually contains 120 constituents, but TRAM only references the above 36 constituents.

CHAPTER 4

DEVELOPMENT OF DATA FOR DERIVING DISTRIBUTIONS OF RISK ESTIMATES

In this chapter we describe the methods and data we used to develop the distributions of risk estimates needed to compare the regulatory scenarios. These distributions are meant to represent the range of risk estimates associated with a tank technology. To generate these distributions, we compiled relevant information on the population of existing hazardous waste tanks and used this information to develop representative model hazardous waste tanks, hydrogeologic settings, and waste streams, and to determine the percentage of the existing tank population that corresponds to each model tank characterization. These percentages were used to weight the risk estimates corresponding to each tank characterization. We then used these weighted risk estimates to derive a distribution of risk estimates.

In the first section of this chapter we describe what we mean by a distribution of risk estimates and outline the methodology we used to develop representative distributions. In Section 4.2 we describe the development of the model tank technologies. Then, in Sections 4.3 through 4.5 we describe the methodologies used to select the representative waste streams, map the tank population into hydrogeologic settings, and select representative release profiles.

4.1 DISTRIBUTIONS OF RISK ESTIMATES

In this section we describe the data and method used to derive representative distributions of risk estimates. We begin by briefly reviewing the interpretation of the risk estimates generated by the Tank Risk Analysis Model (TRAM). We then present and evaluate alternative methods for assessing the benefits of each regulatory scenario. Finally, we describe in detail the method chosen for this study.

4.1.1 Interpretation of Risk Estimates

The TRAM generates chronic human health risk estimates. Specifically, the estimates represent the probable number of individuals per exposed unit of population that will suffer a specific health effect. For example, a risk estimate of 0.01 for cancer implies that 1 in 100 exposed individuals is likely to contract cancer as a result of the exposure. The risk estimates can also be interpreted as the probability that a given exposed individual will contract the specified chronic illness. Thus, the risk estimate of 0.01 for cancer also implies that an exposed individual has a 1 in 100 chance of contracting cancer as result of his or her exposure.

It bears emphasis that the risk estimates apply only to the exposed population, i.e., those individuals who come in contact with the contaminants in question, and not to the entire population of a region. So, for example, if out of a total population of 100 million, 50 million individuals are exposed to the contaminants, and the relevant risk estimate is 0.01, the number of individuals likely to contract the illness specified as a result of the exposure is 500,000 (50 million times 0.01). Because we do not have data on the population of individuals living in the proximity of hazardous waste tanks, we did not estimate the number of individuals likely to contract an illness.

4.1.2 Alternatives for Summarizing Risk Estimates

In order to compare the various regulatory scenarios, we focused attention on developing representative estimates of the human health risk associated with hazardous waste tanks. Because the risk estimates associated with hazardous waste tanks vary considerably, depending on the technical characteristics of the tanks, the wastes they contain, and the hydrogeological characteristics of the areas in which they are located, it is not clear what constitutes a representative risk estimate. We identified two basic options for developing representative risk estimates.

Under the first option, one representative risk estimate would be derived. This representative estimate would be associated with a single tank, waste stream, and hydrogeologic setting. For instance, the representative risk estimate could be based on the most common tank technology, waste stream, and hydrogeologic setting (e.g., a 10,000 gallon carbon steel storage tank containing D001 wastes located over an aquifer with a depth of 30 meters, and a velocity of 10 meters per year). Although such an estimate would be easy to obtain from a computational standpoint once the suitable tank technology, waste stream, and hydrogeologic setting had been chosen, it has two major drawbacks. First, choosing the appropriate tank technology, waste stream, and hydrogeological setting is likely to be difficult and controversial. Second, the estimate would not reflect the considerable variation in risks associated with hazardous waste tanks, and is, therefore, likely to be misleading.

The second option would be to base representative risk estimates on a range of risk estimates for several different tank technologies, hazardous wastes, and hydrogeologic settings. For example, risk estimates for several representative tank technologies, waste streams (for each technology), and predominant hydrogeological settings, could be combined in a suitable manner to obtain a range of risk estimates. Of course, the estimates obtained would depend on the chosen set of specific tanks, waste streams, and hydrogeologic settings. In addition, the computational burden of this approach is undoubtedly higher than that of the first one. However, representative risk estimates derived using the second approach are likely to better reflect the variation in risks associated with hazardous waste tanks. For this reason, the second option was adopted in this study to derive representative risk estimates. A detailed description of the method used to derive the estimates is provided below.

4.1.3 Individual Risk Estimates Underlying the Distribution

We derived risk estimates for numerous combinations of tank technologies, waste streams, and hydrogeological settings. We considered four major categories of tank technologies: storage tanks, treatment tanks, accumulation tanks, and small quantity generator (SQG) tanks. Within each of these four categories, tanks are characterized by:

- the material they are made of -- carbon steel, stainless steel, concrete, or fiberglass reinforced plastic (FRP);
- their location -- above-ground, underground, or in-ground;
- their capacity; and
- whether they are open or closed topped.

In total, we modeled 22 different tank technologies under each of the regulatory scenarios. For each of the 22 tank technologies, the Hazardous Waste Tank Failure Model generated 250 release profiles, with each profile consisting of a series of 20 numbers representing the annual volume of waste released from the tank during a 20-year time horizon. We chose five or six representative profiles from each set of 250 release profiles to depict the typical performance of each model tank. (The method used is described in Section 4.5.) Thus, for each of the 22 technologies modeled under the different regulatory scenarios, five or six representative profiles were selected. The release profiles are the basic inputs to the Tank Risk Analysis Model. Within the risk model, a given tank technology could contain any one of up to 21 different waste streams and be located in any one of 9 possible hydrogeologic settings.

For a given combination of (1) regulatory scenario, (2) tank technology, (3) representative release profile, (4) waste stream, and (5) hydrogeologic setting, the risk model generates annual risk estimates for several different chronic illnesses (e.g., kidney or liver related illness) over a 400-year period. An average annual risk estimate is generated for each constituent in the waste stream. (The precise illnesses depend on the constituents of the wastes contained in the tank.) Of these average risk estimates for each constituent, we selected the highest estimate, which we shall refer to as the dominant risk estimate, to be used for the derivation of the distribution of risk estimates.[1] We use the dominant risk to summarize the risk associated with a particular combination of tank technology, waste stream, hydrogeologic setting and release profile. Thus, for each of the approximately 35,640 combinations of regulatory scenario, tank technology, release profile, waste stream, and hydrogeologic setting, we obtained a dominant risk estimate.[2]

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[1] Of note is that we did not differentiate between carcinogenic and non-carcinogenic risk estimates.

We chose the dominant risk approach to summarize the risk associated with a particular combination of tank technology, waste stream, and hydrogelogic setting, for several reasons. First, while there are as many as six toxic constituents in some of the waste streams selected for the study, risk tends to be dominated in most cases by one or two chemicals due to differences in potency and concentration. Furthermore, summing risk estimtes of different orders of magnitude does not have a significant effect on the outcome, particularly when one considers that the uncertainty inherent in the models used to obtain these estimates restricts their use to relative order-of-magnitude comparisons.

Also, we did not sum risk estimates because, for comparative purposes, we chose not to differentiate between carcinogenic and non-carcinogenic risks and between different effects for non-carcinogenic risks. Many toxicologists consider carcinogenic risks to be additive in the absence of information to the contrary; therefore, if we had only considered carcinogenic risks, summing risk estimates would have been considered acceptable.[3] However, not only did we consider both carcinogenic and non-carcinogenic risks, but we also considered different non-carcinogenic effects. Summary of carcinogenic and non-carcinogenic risks or of non-carcinogenic risks for different effects would ignore probable differences in mechanisms and severity.

For these reasons, and because our analysis focused on relative risk comparisons rather than the estimation of absolute risks, we considered choosing the dominant risk estimate for a particular waste stream-representative release profile-hydrogeologic setting combination to be an adequate representation. This assumption is consistent across all scenarios.

4.1.4 Weighting Dominant Risk Estimates

For a given regulatory scenario and tank technology, we assigned each dominant risk estimate a weight reflecting its likelihood of occurrence. These weights sum to one for a given regulatory scenario and technology (e.g., the weights assigned to the dominant risk estimates for underground, carbon steel storage tanks with secondary containment sum to one). We calculated the dominant risk estimate weights by multiplying the weights for the relevant representative release profile, waste stream, and hydrogeologic setting. We shall refer to the weights used to calculate the dominant risk estimate weights as the component weights (e.g., the hydrogeologic setting weight). An example illustrating the computation of the dominant risk estimate weights is presented below. First, however, we briefly describe the component weights used in computing the dominant risk estimate weights. These component weights are the (1) hydrogeologic setting weights, (2) waste stream weights, (3) representative release profile weights, and (4) tank technology weights.

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[2] The approximate number of combinations is given by: 5 regulatory scenarios x 22 tank technologies x 6 representative profiles x 6 waste streams x 9 hydrogeologic settings = 35,640. The number is approximate because only 5 representative profiles and fewer or more than 6 waste streams were used for some tank technologies. In addition, not all regulatory scenarios are applicable to all of the 22 tank technologies.

[3] The summation of cancer risks would be consistent with EPA's draft risk assessment guidelines for carcinogens (see Federal Register 49:46294-46301, November 17, 1984).

Hydrogeologic Setting Weights. The hydrogeologic setting weights reflect the proportion of a particular category of tanks (i.e., treatment, storage, SQG, or accumulation tanks) located in each of the nine hydrogeologic settings. No readily available, detailed information exists on the location of each modeled tank. Consequently, weights for the hydrogeologic settings were only compiled for each category of modeled tank. These weights are presented in Exhibit 4-1. The weights sum to one for a given category of tanks. (See Section 4.4 for a description of the derivation of the hydrogeologic setting weights.)

Waste Stream Weights. A waste stream weight indicates the proportion of a tank technology population that is assumed to handle the waste stream. For instance, a waste stream weight of 0.24 for D002 handled in in-ground, carbon steel storage tanks, indicates that 24 percent of these tanks are assumed to store D002 wastes. As an example, the waste stream weights corresponding to in-ground, carbon steel storage tanks are presented in Exhibit 4-2. For a given tank technology, the weights sum to one.

Representative Release Profile Weights. As noted earlier, the Hazardous Waste Tank Failure Model generates 250 release profiles for each of the 22 tank technologies (under each regulatory scenario). We divided each set of 250 profiles into 5 or 6 clusters of similar profiles. We then selected one representative profile from each of the clusters (the procedure is described in Section 4.5). These representative profiles were assigned weights equal to the proportion of profiles in the cluster from which they were drawn. Exhibit 4-3 provides an example of this weighting scheme.

We assume that each representative release profile represents the releases associated with a portion (given by the weight) of the modeled tank population. For the example illustrated in Exhibit 4-3, 7.2 percent of all tanks, represented by the modeled tank technology, have releases as indicated by the representative release profile identified for cluster 1.

Tank Technology Weights. The tank technology weights reflect the assumed distribution of tank technologies within a given tank category. These weights are presented in Exhibit 4-4. The weights sum to one for each category of tank. For example, above-ground, carbon steel tanks are assumed to account for 47.6 percent of all small quantity generator (SQG) tanks. Moreover, the weights for SQG tanks sum to one, 0.476 + 0.524 = 1. We have not used these weights in any analysis performed to date. However, these

EXHIBIT 4-1

PERCENTAGE OF TANK CATEGORY LOCATED IN EACH GROUND-WATER SCENARIO

Tank Category	Ground-water Scenario A	B	C	D	E	F	G	H	I
Treatment	0.1068	0.1454	0.1555	0.0724	0.0390	0.1444	0.1452	0.0346	0.1564
Storage	0.1103	0.1440	0.1515	0.0720	0.0420	0.1430	0.1427	0.0358	0.1590
Small Quantity Generators	0.1018	0.1500	0.1583	0.0767	0.0359	0.1482	0.1412	0.0391	0.1484
Accumulation	0.1103	0.1440	0.1515	0.0720	0.0420	0.1430	0.1427	0.0358	0.1590

EXHIBIT 4-2

WASTE STREAM WEIGHTS FOR IN-GROUND, CARBON STEEL STORAGE TANKS

Waste Stream	Waste Stream Weight
D002	0.24
D007	0.27
K048	0.04
F006	0.03
D004	0.38
P115	0.01
K062	0.03

EXHIBIT 4-3

CALCULATING REPRESENTATIVE RELEASE PROFILE WEIGHTS FOR A TANK TECHNOLOGY

Cluster	Number of Profiles in Cluster	Representative Profile Weight
1	18	0.072
2	22	0.088
3	60	0.240
4	50	0.200
5	43	0.172
6	57	0.228
Total	250	1.000

EXHIBIT 4-4

TANK TECHNOLOGY WEIGHTS

Tank Category	Tank Technology	Weight
Treatment	Above-ground, closed top, carbon steel	0.238
	Above-ground, open top, carbon steel	0.358
	Above-ground, ongrade, carbon steel	0.067
	In-ground, concrete	0.198
	In-ground, carbon steel	0.054
	In-ground, stainless steel	0.085
Storage	Above-ground, on cradles, carbon steel	0.582
	Above-ground, ongrade, carbon steel	0.155
	Underground, carbon steel	0.149
	Underground, FRP	0.018
	Underground, stainless steel	0.020
	In-ground, concrete	0.048
	In-ground, carbon steel	0.029
Small Quantity Generator	Above-ground, carbon steel	0.476
	Underground, carbon steel	0.524
Accumulation	Above-ground, on cradles, carbon steel	0.582
	Above-ground, ongrade, carbon steel	0.155
	Underground, carbon steel	0.149
	Underground, FRP	0.018
	Underground, stainless steel	0.020
	In-ground, concrete	0.048
	In-ground, carbon steel	0.029

weights give us the option of summarizing the risk estimates for a category of tanks. For example, we could use these weights to derive a distribution of risks associated with all different types of small quantity generator tanks.

Calculating Dominant Risk Estimate Weights. As noted earlier, the dominant risk estimate weights are obtained by multiplying the relevant component weights. The exact procedure is best illustrated by an example. Suppose the dominant risk estimate for the third representative release profile for an in-ground, concrete treatment tank when located in hydrogeologic setting C and storing D001 wastes is 0.00001. The component weights for calculating the weight to be applied to this dominant risk estimate are presented in Exhibit 4-5. As shown, the weight associated with the dominant risk estimate is equal to the product of three component weights.

The weights indicate that: (1) 15.55 percent of all in-ground, concrete treatment tanks are located in hydrogeologic setting C; (2) 29.4 percent of all in-ground, concrete treatment tanks handle waste stream D003; and (3) representative release profile 3 is representative of the types of releases that are associated with 19.3 percent of all in-ground, concrete treatment tanks. The product of these three weights (i.e., 0.0088) indicates the percent (i.e., .88 percent) of all in-ground, concrete treatment tanks that are associated with the following characterization: (1) are located in hydrogeologic setting C; (2) handle waste stream D003; and (3) have releases as indicated by representative release profile 3. In summary, this example illustrates that .88 percent of all in-ground, concrete treatment tanks are associated with a risk estimate of 0.00001.

4.1.5 Deriving the Frequency Distribution of Dominant Risk Estimates

Using the procedure described above, we calculated weights for each of the dominant risk estimates. For a given tank technology and regulatory scenario, we then used the dominant risk estimates and their weights to develop frequency distributions of dominant risk. The derivation of the frequency distribution is best demonstrated via a hypothetical example. Exhibit 4-6 contains the hypothetical dominant risk estimates and their weights for an above-ground, carbon steel SQG tank. For illustrative purposes, we have reduced the number of hydrogeological settings, representative release profiles and waste streams associated with this hypothetical tank. Consequently, we assumed that there are only two relevant waste streams, two representative profiles, and two hydrogeologic settings. Therefore, in this example there are eight dominant risk estimates (two representative profiles x two waste streams x two hydrogeologic settings). These eight risk estimates indicate a hypothetical range of dominant risk estimates associated with an above-ground, carbon steel small quantity generator tank.

The dominant risk estimates in Exhibit 4-6 are arranged in a frequency distribution in Exhibit 4-7. This distribution can be viewed as a hypothetical frequency distribution of dominant risk estimates associated with an aboveground, carbon steel small quantity generator tank. The vertical scale of the figure gives dominant risk and the horizontal scale gives

EXHIBIT 4-5

SAMPLE CALCULATION OF DOMINANT RISK ESTIMATE WEIGHT

Variable	Weight
Hydrogeologic Setting C	0.1555
D003 Waste Stream	0.2940
Representative Profile 3	0.1930
Dominant Risk	0.0088 = 0.1555 x 0.2940 x 0.1930

relative frequency. The relative frequency for a given range of dominant risk estimates (e.g., 5 x 10^{-5} to 5 x 10^{-4}) is equal to the sum of the weights associated with dominant risk estimates in that range. For example, in Exhibit 4-6, two dominant risk estimates are within the range 5 x 10^{-5} to 5 x 10^{-4} (specifically, 8 x 10^{-5} and 2 x 10^{-4}), and their weights sum to 0.425 (0.125 + 0.300), as shown in Exhibit 4-7. By construction, the relative frequency of the four "bars" in Exhibit 4-7 sum to one.

Frequency distributions such as the one depicted in Exhibit 4-7 were prepared for each tank technology under each regulatory scenario, yielding a total of approximately 110 (twenty-two technologies x five regulatory scenarios) frequency distributions.* In order to compare the range of dominant risk estimates for each of these 110 combinations of tank technology and regulatory scenario, suitable summary measures must be chosen for the frequency distributions of dominant risk estimates. The two most common summary measures are the mean and the median. The mean of a dominant risk estimate distribution is equal to the sum of the products of each risk estimate and its weight. A simple example is provided in Exhibit 4-8. The median dominant risk estimate is the risk estimate such that (roughly) 50 percent of the weight of the distribution is accounted for by risk estimates greater than or equal to it and 50 percent by risk estimates less than or equal to it. The derivation of the median is also illustrated in Exhibit 4-8. The median dominant risk estimate can be interpreted as the dominant risk estimate such that 50 percent of the time the actual dominant risk estimate exceeds it and 50 percent of the time it is lower than it. For example, if the median dominant risk estimate is 0.001, the actual dominant risk estimate will exceed 0.001 50 percent of the time, and be lower than 0.001 50 percent of the time.

The example presented in Exhibit 4-8 demonstrates that the mean and median of a distribution can differ considerably (mean = 0.0001043, median = 0.000001). The mean is approximately two orders of magnitude higher than the median. In general, the value of the mean dominant risk estimate will be more sensitive than the median to extreme dominant risk estimate values with small weights. In the example presented, the mean dominant risk estimate primarily reflects the dominant risk estimate of 0.001. But note that 90 percent of the dominant risk estimates are lower than the mean dominant risk estimate. The choice between the mean and median as a summary measure for dominant risk estimates will depend largely on the importance that is given to extreme dominant risk estimates with low weights.

An alternative to either the mean or the median that may be a suitable summary measure, given the characteristics of the dominant risk estimate distributions obtained, is the proportion of non-zero risk dominant estimates. For example, if the dominant risk estimates obtained are (0,

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*The number of frequency distributions is approximate because all the regulatory scenarios are not applicable to each tank technology. For example, partial containment is not applicable to above-ground, on cradles tank technologies.

EXHIBIT 4-6

HYPOTHETICAL DOMINANT RISK ESTIMATES AND THEIR WEIGHTS FOR ABOVE-GROUND, CARBON STEEL SQG TANK

Hydrogeologic Setting	Representative Profile	Dominant Risk Estimate F001 Waste Stream	Dominant Risk Estimate X900 Waste Stream
A	1	3×10^{-3} (0.025)	8×10^{-5} (0.125)
	2	4×10^{-5} (0.050)	6×10^{-6} (0.250)
B	1	2×10^{-4} (0.300)	3×10^{-5} (0.066)
	2	2×10^{-6} (0.150)	6×10^{-7} (0.034)

Note: Weights are presented in parentheses.

EXHIBIT 4-7

HYPOTHETICAL FREQUENCY DISTRIBUTION OF RISK ESTIMATES FOR ABOVE-GROUND, CARBON STEEL SQG TANK

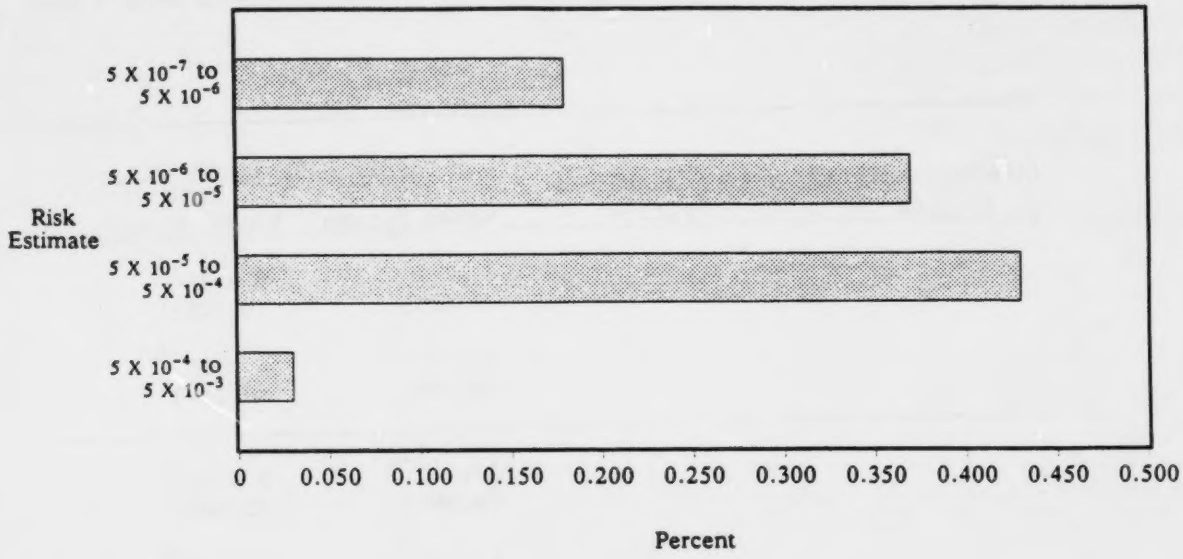

EXHIBIT 4-8

MEAN AND MEDIAN OF DOMINANT RISK DISTRIBUTION

Risk Estimate	Weight	Cumulative Weight	Risk Estimate x Weight
10^{-8}	0.10	0.10	1.0×10^{-9}
10^{-7}	0.15	0.25	1.5×10^{-8}
10^{-6}	0.25	0.50	2.5×10^{-7}
10^{-5}	0.10	0.60	1.0×10^{-6}
10^{-5}	0.15	0.75	1.5×10^{-6}
10^{-5}	0.15	0.90	1.5×10^{-6}
10^{-3}	0.10	1.00	1.0×10^{-4}
	Median = 10^{-6}	Mean = 1.043×10^{-4}	

10^{-7}, 10^{-6}, 10^{-6}), the proportion of non-zero dominant risk estimates is 0.75. If limited importance is given to the precise magnitude of non-zero dominant risk estimates, the proportion of non-zero dominant risk estimates is a useful summary measure for the dominant risk estimate distribution.

Although single summary measures such as the mean, median, or proportion of non-zero dominant risk estimates are convenient, they generally fail to adequately reflect all the relevant features of a frequency distribution, as the example presented above demonstrates. An alternative to using a single summary measure is to use several, such as the 25th percentile, the 50th percentile, and the 75th percentile of the distribution. For the example in Exhibit 4-8 we would have:

Percentile	Dominant Risk Estimate
25th	10^{-7}
50th	10^{-6}
75th	10^{-5}

Thus, 25 percent of the time, dominant risk estimates are less than or equal to 10^{-7}, 50 percent of the time they are less than or equal to 10^{-6}, and 75 percent of the time they are less than or equal to 10^{-5}. (Note that, by definition, the 50th percentile is equal to the median.) This approach to summarizing frequency distributions of dominant risk estimates, although slightly more cumbersome, will reflect the variation in dominant risk estimates.

Having discussed the construction and interpretation of dominant risk estimate distributions, the remainder of this chapter is devoted to examining the data needed to derive the frequency distributions.

4.2 DEVELOPMENT OF MODEL TANKS

4.2.1 Introduction

To estimate the human health risks associated with alternative regulatory requirements for hazardous waste tanks, we developed 22 model tanks that represent typical tanks in the Office of Solid Waste Regulatory Impact Analysis Tank Survey (OSW RIA) and the Small Quantity Generator Survey (SQG Survey). These models represent typical tanks for each of four categories of hazardous waste tanks: (1) storage; (2) treatment (excluding wastewater treatment tanks); (3) accumulation (storage for less than 90 days at facilities that generate more than 1000 kg of waste per month); and (4) small quantity generators (that generate between 100 and 1000 kg of hazardous waste per month).

We identified model tank technologies for each of these four categories based on differences among tank characteristics, especially type (i.e., above-, in-, or underground) and material of construction (e.g., carbon steel, stainless steel, concrete, fiberglass reinforced plastic), that affect risks, and on the data available to describe each category. We selected the 22 model tank technologies to represent the predominant tank types and materials of construction for each of the four tank categories listed above in order to minimize the number of model tanks developed. It was important to minimize the number of model tanks included in the analyis due to the complexity of the release, transport, and exposure calculations that are required.

The basic steps we used in developing the model tank technologies are as follows:

- Define the tank categories of interest (i.e., SQG, storage, accumulation and treatment);
- Determine the tank characteristics most likely to affect releases to the environment and compliance costs;
- Identify the data available to describe these tank characteristics; and
- Analyze the available data to describe the population and select appropriate model tanks.

In the remainder of section 4.2 we discuss the selection of the model tanks in more detail, present the characteristics of the model tanks selected, and highlight the limitations and assumptions that are incorporated in the development of the model tanks.

4.2.2 Methodology

The purpose of the selection methodology was to minimize the number of model tanks that would adequately represent the national population of tanks. To ensure that the development of model tanks reflected the objectives of the risk analysis effort, we first considered the regulatory requirements to be examined by the model. Consideration of these requirements (e.g., secondary containment, ground-water monitoring, corrosion protection, leak testing, initial integrity assessment) provided general information on the type of tank characteristics that needed representation.

Next, we identified the types of tanks that would be subject to the requirements of the hazardous waste tank rulemaking. First, we identified three broad categories of facilities with hazardous waste tanks: (1) RCRA interim status or permitted hazardous waste storage or treatment tank facilities; (2) facilities that generate more than 1000 kg of hazardous waste per month and accumulate hazardous waste in tanks for periods of less than 90 days; and (3) small quantity generator facilities that generate between 100 and 1000 kg of hazardous waste per month and use tanks to store or treat the waste.

We then identified the types of tank characteristics that influence the frequency and magnitude of releases from tanks to further characterize the model tanks.[5,6,7,8] The characteristics identified include tank type (i.e., above-ground, underground, in-ground), use (e.g., accumulation, storage or treatment), design capacity, quantity of waste contained, type of waste contained, material of construction, operating procedures (e.g., inspection schedules, inventory control practices), age, safety features (e.g., overfill protection devices), installation practices, design features (e.g., secondary containment), and piping length.

The next step in the development of model tanks was to identify readily available sources of information that would describe as many of the tank characteristics of interest as possible for each of the three broad categories of facilities potentially affected by the proposed rulemaking. We used the OSW RIA Generator Survey, Tank Survey and SQG Survey as the most direct sources of the appropriate information. Although these were the best available data sources, the information on hazardous waste tanks contained in these sources is inconsistent with respect to the level of detail provided. In particular, the Generator Survey provides information on the number of accumulation tanks used nationwide, the number of tanks per facility and the average size of the tanks, while the SQG survey provides information on the number of facilities with tanks, the types of waste managed in the tanks, the average storage period, and the tank throughput. The Tank Survey, on the other hand, provides information on many of the tank characteristics of interest.

Based on the available data sources and consideration of the analytical complexity (and the associated need to minimize the number of model tank facilities selected for analysis, we decided to describe each model tank in terms of tank type (i.e., above-, in-, or underground), design capacity, material of construction, age, the median number of tanks at facilities with each type of model tank, and whether the tank is open- or closed-topped. The use of the available data to describe the model tanks in terms of these selected characteristics is described below for each of the three hazardous

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[5] F. G. Bercha and Associates, Limited, Bulk Plant Risk Optimization, report for the Environmental Protection Service, Hull, Quebec, December 1982.

[6] JRB Associates, Failure Incident Analysis: Evaluation of Storage Failure Points, a report to the Office of Solid Waste, EPA, 1982.

[7] SCS Engineers, Assessment of the Technical, Environmental, and Safety Aspects of Storage of Hazardous Waste in Underground Tanks, a report to the Office of Solid Waste, EPA, 1984.

[8] SCS Engineers, Assessment of the Technical, Environmental, and Management Aspects of Storage and Treatment of Hazardous Waste in Aboveground and Underground Tanks, a report to the Office of Solid Waste, EPA, August 1984.

waste tank facility categories identified above. We present RCRA storage and treatment tanks separately because experience and the available data indicate that these are distinct tank populations. In addition, we present our estimation of the type and length of piping associated with the model facilities.

Storage Tanks

We first selected model storage tanks by categorizing the storage tanks (from the OSW RIA data base) by tank type and material of construction as shown in Exhibit 4-9. We used two categories of above-ground tanks because we assume that above-ground tanks less than or equal to 25,000 gallons are installed off the ground on cradles or legs and that tanks larger than 25,000 gallons are installed on-grade.[9] We then identified the combinations of tank type and material that best represent the storage tank population.

As shown in Exhibit 4-9, nearly 80 percent of above-ground tanks with capacities less than 25,000 gallons are made of carbon steel. Thus, we selected carbon steel as the material of construction for the entire population of above-ground tanks with capacities less than 25,000 gallons. We did not model tanks with capacities less than 25,000 gallons that are made from other materials because they each represent a small proportion of this type of tank.

For above-ground tanks larger than 25,000 gallons, we also selected carbon steel as the construction material for the model tank because 94 percent of these types of tanks are constructed with carbon steel. For in-ground tanks, Exhibit 4-9 shows that both concrete and carbon steel are commonly used. Based on these data and judgement concerning the impacts of tank material on risks for in-ground tanks, we selected concrete and carbon steel in-ground model tanks to represent 62.3 and 47.7 percent of the in-ground storage tank population, respectively.

For underground tanks, Exhibit 4-9 shows that carbon steel is the most common construction material, followed by stainless steel, fiberglass, concrete and "other". Based on these data and judgement, we selected carbon steel, stainless steel, and fiberglass model tanks to represent 79.8, 10.6 and 9.6 percent of the underground storage tank population, respectively.

Next, we obtained data on the distribution of tank size, age and top (closed or open), and the median number of tanks at facilities with storage tanks for each of the following four types of tanks:

- Above-ground storage tanks less than 25,000 gallons;

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[9] ICF Incorporated, Estimated Costs of Compliance with Proposed RCRA Regulations for Hazardous Waste Storage, Treatment, and Accumulation Tank Facilities, a draft report to the Office of Solid Waste, EPA, March 1985.

EXHIBIT 4-9

DISTRIBUTION OF STORAGE TANKS BY TYPE AND MATERIAL OF CONSTRUCTION

	Frequency of Occurrence/Percent of All Storage Tanks/Percent of Type of Storage Tanks/Percent of Storage Tank Material of Construction						
	Material of Construction						
Type	Carbon Steel	Stainless Steel	Concrete	Fiberglass	Aluminum	Other a/	Total b/
Above-ground (< 25,000 gal.)	2,314	292	21	251	9	68	2,955
	45.5	5.7	0.4	4.9	0.2	1.3	58.2
	78.3	9.9	0.7	8.5	0.3	2.3	
	61.0	65.8	6.3	70.1	10.0	46.9	
Above-ground (> 25,000 gal.)	740	28	1	0	0	9	787
	14.6	0.6	0.2	0	0	0.2	15.5
	94.0	3.6	1.3	0	0	1.1	
	19.5	6.3	3.0	0	0	6.2	
In-ground	104	23	243	16	0	4	390
	2.0	0.5	4.8	0.3	0	0.1	7.7
	26.7	5.9	62.3	4.1	0	1.0	
	2.7	5.2	72.5	4.5	0	2.8	
Underground	632	101	61	91	0	64	949
	12.4	2.0	1.2	1.8	0	1.3	18.7
	66.6	10.6	6.4	9.6	0	6.7	
	16.7	22.7	18.2	25.4	0	44.1	
TOTAL	3,790	444	335	358	9	145	5,081 c/
	74.6	8.7	6.6	7.0	0.2	2.9	100

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a/ Tanks indicated by the survey respondents to be made of wood or "other" materials.

b/ Totals may not agree with source data due to rounding.

c/ Does not include 210 "other" types and 164 "Not Accounted For"; total = 5,455.

Source: OSW RIA Tank Survey Data Base.

- Above-ground storage tanks larger than 25,000 gallons;
- In-ground storage tanks; and
- Underground storage tanks.

We considered obtaining these data separately for each of the seven selected model storage tanks. Our review of the survey methodology used to develop the OSW RIA Data Base, however, indicated that these data would not support distinctions among tanks of the same type that are constructed of different materials. Based on the data obtained, we characterized the seven model storage tanks as follows:

Location	Material	Open or Closed Top	Median Age (Years)	Median Size (Gallons)	Tanks Per Facility a/
Above-ground ≤25,000	Carbon steel	Closed	6	5,500	4
Above-ground ≥25,000	Carbon steel	Closed	21	210,000	4
Underground	Carbon steel	--	7	4,000	4
Underground	Fiberglass	--	7	4,000	4
Underground	Stainless steel	--	7	4,000	4
In-ground	Concrete	Open	8	2,100	4
In-ground	Concrete	Carbon steel	8	2,100	4

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a/ Median number of tanks of all types per facility with storage tanks.

Treatment Tanks

The procedure we used to select model treatment tanks was essentially identical to that for storage tanks because the source of readily available data is the same. Data from the OSW RIA Data Base on tank type and material is summarized in Exhibit 4-10. As shown, the majority of above-ground tanks less than 25,000 gallons are made of carbon steel. Thus, we selected a carbon steel model tank to represent the entire population of above-ground treatment tanks with capacities less than 25,000 gallons.

EXHIBIT 4-10

DISTRIBUTION OF TREATMENT TANKS BY TYPE AND MATERIAL OF CONSTRUCTION

Type	Frequency of Occurrence/Percent of All Treatment Tanks/Percent of Type of Treatment Tanks/Percent of Treatment Tank Material of Construction						
	Material of Construction						
	Carbon Steel	Stainless Steel	Concrete	Fiberglass	Aluminum	Other	Total a/
Above-ground (< 25,000 gal.)	1,317	160	74	320	13	107	1,991
	39.4	4.8	2.2	9.6	0.4	3.2	59.6
	66.1	8.0	3.7	16.1	0.6	5.4	
	80.2	38.1	9.7	89.9	40.6	81.7	
Above-ground (>25,000 gal.)	181	12	26	--	--	4	223
	5.4	0.4	0.8	--	--	0.1	6.7
	81.2	5.4	11.7	--	--	1.8	
	11.0	2.9	3.4	--	--	3.1	
In-ground	132	248	606	36	19	15	1,056
	4.0	7.4	18.1	1.1	0.6	0.4	31.6
	12.5	23.5	57.4	3.4	1.8	1.4	
	8.0	59.0	79.5	10.1	59.4	11.5	
Underground	12	0	56	0	0	5	73
	0.4	0	1.7	0	0	0.1	2.2
	16.4	0	76.7	0	0	6.8	
	0.7	0	7.3	0	0	3.8	
TOTAL	1,642	420	762	356	32	131	3,343 b/
	49.1	12.6	22.8	10.6	1.0	3.9	100

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a/ Totals may not agree with source data due to rounding.

b/ Does not include 41 "other" types and 185 "Not Accounted For"; total = 3,569.

Source: OSW RIA Tank Survey Data Base.

For above-ground treatment tanks larger than 25,000 gallons, we also selected carbon steel as the construction material for the model tank because the vast majority (81.2 percent) of this type of tank are constructed with carbon steel. For in-ground tanks, Exhibit 4-2 shows that concrete, stainless steel and carbon steel are all relatively common. In addition, Exhibit 4-2 shows that underground tanks comprise only a very small portion of the treatment tank population. Thus, we decided to let underground treatment tanks be represented by in-ground model tanks. Based on these data, we selected concrete, stainless steel and carbon steel in-ground model tanks to represent 58.6, 25.2, and 16.2 percent of the combined in-ground and underground treatment tank population, respectively.

Next, we obtained information from the OSW RIA Data Base on the distribution of tank size, age, and top (closed or open), and the median number of tanks at facilities with treatment tanks for each of the following three types of treatment tanks:

- Above-ground treatment tanks smaller than 25,000 gallons;
- Above-ground treatment tanks larger than 25,000 gallons; and
- In-ground treatment tanks.

We used these data to further characterize each of the selected model treatment tanks in a manner identical to that described above for storage tanks. Additional information from the data base on commonly used treatment technologies was also used.

The data on treatment technologies indicated that two treatment processes most commonly associated with above-ground tanks less than 25,000 gallons are distillation and oxidation/reduction/precipitation. Because distillation requires a closed-top tank while oxidation/reduction/precipitation is normally conducted in open tanks, we used two model treatment tanks to represent above-ground treatment tanks less than 25,000 gallons. Because 60 percent of the above-ground treatment tanks less than 25,000 gallons are open-topped, the open-top model tank represents 35.8 percent (0.6 x 59.6) of the treatment tank population while the closed-top model tank represents 23.8 percent (0.4 x 59.6) of the population.

The resulting model treatment tank characteristics are as follows:

Location	Material	Open or Closed Top	Median Age (Years)	Median Size (Gallons)	Tanks Per Facility a/
Above-ground ≤25,000 gal.	Carbon steel	Open	5	2,300	5
Above-ground ≤25,000 gal.	Carbon steel	Closed	5	2,300	5
Above-ground ≥25,000 gal.	Carbon steel	Open	9	60,000	5
In-ground	Concrete	Open	10	3,700	5
In-ground	Carbon steel	Open	10	3,700	5
In-ground	Stainless steel	Open	10	3,700	5

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a/ Median number of tanks of all types per facility with treatment tanks.

Accumulation Tanks

Data collected as part of the OSW RIA Generator Survey and maintained in the OSW RIA Data Base indicate that the accumulation tank population consists of approximately 6,400 tanks. The data base, however, does not provide information on tank capacity, material of construction, age or other characteristics of interest for estimating human health risks. Thus, we chose to represent accumulation tanks in this analysis with the same seven model tanks presented above for storage tanks. In doing so, we also assumed that these seven model tanks are distributed the same for both accumulation and storage tanks (e.g., the concrete in-ground model tank represents 4.8 percent of all accumulation tanks).

Small Quantity Generator (SQG) Tanks

As noted above, the source of readily available information on the population of tanks used to store hazardous waste at facilities that generate between 100 and 1000 kg per month of hazardous waste is the OSW SQG Survey.[10] The survey indicates that there are about 9,240 SQG facilities with tanks in the primary Standard Industrial Classifications (SICs) included in the SQG Survey. Inclusion of information from the survey on secondary SICs increases the total number of facilities with tanks to 11,388. The distribution of these 11,388 facilities with above-ground and underground tanks is as follows:

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[10] Abt Associates, Inc., National Small Quantity Hazardous Waste Generator Survey, EPA, 1985.

Type of Tank	Number of Faciliites
Above-ground only	4,745
Underground only	4,935
Both above-ground and underground	1,708
TOTAL	11,388

However, the data do not indicate the number of tanks at each facility. For this analysis, we assumed that each facility has two tanks, so the total SQG tank population is estimated to be 22,776, or about 23,000. We believe that this is a conservative (i.e., high-side) assumption because our experience indicates that there are relatively few instances in which quantities of waste generated by a small quantity generator facility will be large enough to require two tanks.

The survey also does not provide information on tank construction materials. Because the data presented in Exhibits 4-9 and 4-10, and engineering judgement, indicate that the vast majority of hazardous waste tanks are carbon steel, we selected carbon steel as the construction material for both the underground and above-ground SQG model tanks.

The survey does provide some information on tank size in that it indicates the average amount of waste generated per month and the average storage duration. Using these data for facilities that only store wastes in tanks, we calculated the estimated tank size distributions shown in Exhibit 4-11.[11] We assumed that all SQG tanks will be operated as accumulation tanks (to avoid the need to obtain a RCRA storage permit) if the proposed tank standards are applied to SQG facilities. Therefore, we used the distribution for above-ground tanks that store for less than 180 days as the basis for the SQG

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[11] We estimated tank capacity by assuming that it was equal to the average quantity of waste accumulated before it is removed for disposal. We calculated the average quantity of waste accumulated by multiplying the storage time in months by the storage rate in kg/mo. We converted the resulting waste quantity (in kg) to gallons using a conversion factor of 0.2688519 (which assumes a waste specific gravity equal to that of water).

EXHIBIT 4-11

SQG TANK SIZE DISTRIBUTIONS

Above-ground Tanks (greater than 180-day storage)

Size (Gallons)	Cumulative Percent
500	15
750	82
1,500	88
1,750	100

Above-ground Tanks (less than 180-day storage)

Size (Gallons)	Cumulative Percent
≤50	18
100	31
250	82
500	90
1,000	98
1,500	100

Underground Tanks

Size (Gallons)	Cumulative Percent
50	25
200	75
500	100

above-ground model tank size. The majority of above-ground SQG tanks (82 percent) appear to be 250 gallons or less and the majority of underground SQG tanks (75 percent) appear to be 200 gallons or less. Thus, we selected 200 gallons as the tank size for both the above-ground and underground SQG model tanks. To characterize tank age, we used the median ages for underground and above-ground storage tanks from the OSW RIA tank survey.

Based on the foregoing data and assumptions, we selected two model tanks to represent the SQG tank population with the following characteristics:

Location	Material	Open or Closed Top	Median Age (Years)	Median Size (Gallons)	Tanks Per Facility a/
Above-ground	Carbon steel	Closed	6	200	2
Underground	Carbon steel	N/A	7	200	2

---

a/ Number of tanks of all types per facility.

Piping

Because some of the regulatory requirements under consideration affect ancillary equipment as well as tanks, development of the model tanks required inclusion of information on associated piping characteristics. Because the data sources discussed above do not contain any information on piping, we obtained additional information and made assumptions as necessary to develop piping characteristics. Based on public comments on the proposed regulations for hazardous waste tanks (50 CFR 26444, June 26, 1985) and conversations with trade associations, tank manufacturers, and other industry representatives, we estimated that a typical storage, treatment, or accumulation tank has 50 feet of piping for each tank if the facility has fewer than 5 tanks and 200 feet of piping per tank if the facility has five or more tanks.

Because somewhat less than half of the facilities have five or more tanks, we used 100 feet as the length of piping associated with each storage, treatment, SQG, and accumulation model tank. In addition, we assumed that all piping associated with underground tanks is underground. For above-ground and in-ground tanks, we assumed that all of the piping is above-ground and located within the tank secondary containment area (if there is one).

For all of the model tanks, we assumed that the piping is made of the same material as the tank, except in the case of concrete tanks where we assumed that the associated piping is carbon steel.

Summary

The cumulative result of the process described above was the selection of 22 model tanks for use in estimating human health risks using the Hazardous Waste Tank Risk Analysis Model. These 22 model tanks are summarized in Exhibit 4-12.

EXHIBIT 4-12

MODEL TANK CHARACTERISTICS SUMMARY

TECHNOLOGY	LOCATION	OPERATING CAPACITY (gallons)	MATERIAL	OPEN OR CLOSED TOP	MEDIAN AGE (Years)	MEDIAN SIZE (gallons)	PERCENTAGE OF TECHNOLOGY
TREATMENT:							
	above-ground; on cradles	<25,000	carbon steel	closed	5	2,300	.238 a/
	above-ground; on cradles	<25,000	carbon steel	open	5	2,300	.358
	above-ground; ongrade	>25,000	carbon steel	open	9	60,000	.067
	in-ground	--	concrete	open	10	3,700	.198
	in-ground	--	carbon steel	open	10	3,700	.054
	in-ground	--	stainless steel	open	10	3,700	.085
STORAGE:							
	above-ground; on cradles	<25,000	carbon steel	closed	6	5,500	.582 b/
	above-ground; ongrade	>25,000	carbon steel	closed	21	210,000	.155
	below-ground	--	carbon steel	--	7	4,000	.149
	below-ground	--	fiberglass	--	7	4,000	.018
	below-ground	--	stainless steel	--	7	4,000	.020
	in-ground	--	concrete	open	8	2,100	.048
	in-ground	--	carbon steel	open	8	2,100	.029
SMALL QUANTITY GENERATORS:							
	above-ground	200	carbon steel	closed	6	200	.476 c/
	below-ground	200	carbon steel	--	7	200	.524
ACCUMULATION:							
	above-ground; on cradles	<25,000	carbon steel	closed	6	5,500	.582 d/
	above-ground; ongrade	>25,000	carbon steel	closed	21	210,000	.155
	below-ground	--	carbon steel	--	7	4,000	.149
	below-ground	--	fiberglass	--	7	4,000	.018
	below-ground	--	stainless steel	--	7	4,000	.020
	in-ground	--	concrete	open	8	2,100	.048
	in-ground	--	carbon steel	open	8	2,100	.029

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a/ Total number of treatment tanks is 3,569.

b/ Total number of storage tanks is 5,455.

c/ Total number of small quantity generator tanks is 22,776.

d/ Total number of accumulation tanks is 6,400.

4.2.3 Assumptions and Limitations

As indicated throughout the preceeding discussion, data limitations required that we make several assumptions in order to select the model tank technologies. The more important of these assumptions are:

- Above-ground tanks with a capacity less than or equal to 25,000 gallons are installed above the ground on legs or cradles;
- Above-ground tanks with a capacity greater than 25,000 gallons are installed ongrade;
- The model storage tanks derived from the OSW RIA Data Base are also representative of accumulation tanks;
- All piping for underground tanks is underground while all piping for above-ground and in-ground tanks is above-ground;
- SQG tanks are all 200 gallon, carbon steel tanks, and either on cradles or completely underground; and
- SQG facilities with tanks have two tanks.

In addition to these assumptions, the approach used to develop the model tanks results in several limitations that have implications for the overall analysis. The most significant limitation is that the approach used does not represent the extremes that exist in the tank population. For example, representing all above-ground storage tanks smaller than 25,000 gallons as carbon steel fails to capture any risk differences that may exist for such tanks made from other materials. Similarly, use of median characteristics such as age and size does not capture the extremes in the population.

4.3 SELECTION OF REPRESENTATIVE WASTE STREAMS

Hazardous waste tanks handle an extremely wide variety of substances, and it is probably safe to assume that any hazardous waste, with the exception of pure gases and solids, may at one time be stored in a tank. However, for the purpose of this analysis, we considered it most important to identify a relatively small number of waste streams that would represent the wastes most commonly stored and treated in hazardous waste tanks. Our objective was to analyze the differences in risk associated with different hazardous wastes handled in tanks, while minimizing the complexity of the analysis. Because our analysis addressed chronic human health risks due to contaminant releases from hazardous waste tanks, we focused only on wastes containing chronically toxic chemicals. Thus, our selection criteria for waste streams included not only total quantity handled in tanks, but also toxicity of the constituents in each waste stream. By selecting waste streams with the most toxic constituents, we were able to obtain conservative risk estimates. We did not consider concentrations of toxic constituents in a particular waste stream in our selection criteria because, although concentration does influence risk, there is a great deal of uncertainty as to the concentration of a constituent in any particular waste, and we were able only to identify generic average values for our analysis.

We did not begin our selection process with any set number of waste streams in mind for any tank category, but rather with the objective of including as representative a sample as possible of wastes handled in tanks without allowing the analysis to become overly computationally intensive. Thus, our general selection methodology ususally involved the compilation of one or more ranked lists of waste streams for a particular category. The number of waste streams for a category was then selected based on an obvious cut-off point (according to total volume handled) in these lists.

For this analysis we identified waste streams for each technology, even though we only had data for each tank category. The most detailed available data characterizes waste streams by tank location (i.e., above-ground or underground). Consequently, we identified waste streams for each tank category using professional judgment and available information on the type of wastes stored in above-ground and underground tanks. We assumed that some wastes streams were incompatible with tank materials.

In this section, we describe the methodologies used to select representative waste streams for each of the four modeled tank categories, and to characterize the selected waste streams. In the following four sections we present the selection methodology and representative waste streams for SQG tanks, RCRA-permitted storage tanks, accumulation tanks, and treatment tanks, respectively.

4.3.1 Small Quantity Generator Tank Waste Streams

Although only a small number of data sources containing information on SQG wastes were available, these sources generally were quite comprehensive in terms of information on waste streams and waste storage and treatment technologies. We identified two major sources:

- National Small Quantity Hazardous Waste Generator Survey, (February, 1985). This survey provides estimates of the number and type of small quantity generators, types of waste generated, and their waste management practices. The report contains data on 22 industry groups and the number of generators in each group, the amount of waste generated, and the percentages of wastes stored and treated on- and off-site. This survey also gives information on the percentage of each waste type stored in above-ground and underground tanks. It does not provide detailed waste characterization information, only general descriptions of the included waste streams.

- Economic Analysis of Resource Conservation and Recovery Act Regulations for Small Quantity Generators, (June, 1985). This report contains information on SQG industries (e.g., dry cleaning), and also includes data on specific SQG waste streams. These data include total quantity generated (kg/month) and total number of generators for each of 39 waste streams; also included for each waste stream are characteristics such as constituents of concern and concentrations.

By combining these data sources, we compiled information on the quantity and number of generators for the most common SQG waste streams, waste stream characteristics (i.e., most toxic constituents, or constituents of concern and concentrations of these constituents), waste stream storage in above-ground or underground tanks, and the relative frequency of occurrence for each waste stream on a nationwide basis, i.e., the percentage of the total SQG waste quantity handled in tanks that each waste stream represents.

Due to the availability of information on SQG waste streams that are stored and/or treated in tanks, the selection of waste streams for inclusion in the Tank Risk Analysis Model was relatively straightforward. We selected waste streams using the following methodology:

- Ranked all SQG waste streams in terms of total waste quantity generated (kg/month) and number of generators.
- Identified which SQG waste streams are stored in tanks.
- Ranked all SQG waste streams that are stored in tanks in terms of total waste quantity generated and total number of generators, and number of tanks storing each waste stream.
- Divided the waste streams into those usually stored in above-ground and underground tanks.
- Characterized each waste stream by its constituents of concern.
- Assigned each waste stream a frequency of occurrence (i.e., percentage of the total SQG waste quantity handled in tanks that each waste stream represents).

We first identified all wastes generated by small quantity generators. We identified 39 waste streams. We then compared the list of generated wastes with wastes that are stored in above-ground or underground tanks. We eliminated from the ranked list all waste streams that are not stored in tanks according to SQG survey data. The SQG waste streams that we eliminated included the highest-ranked waste stream (in terms of quantity and number of generators), lead-acid batteries, and the seventh-ranked waste stream, waste formaldehyde.

To reduce the number of waste streams to be analyzed, we ranked the waste streams according to: 1) the total quantity of waste generated and total in number of generators; and 2) the total number of tanks storing each waste stream. We then assigned a composite ranking to each waste stream based on its position in each of these two lists. The final list of ranked waste streams that we used for this study is illustrated in Exhibit 4-13.

These 16 waste streams were then categorized according to whether they were commonly stored in above-ground or underground tanks. It was found that only one waste stream, waste ink with solvents or heavy metals, was unique to underground tanks, while cyanide wastes, spent plating wastes, solutions or sludges with photo silver, and heavy metal wastewater sludges are stored only in above-ground tanks. The waste streams included in each category are listed in Exhibit 4-14.

Using available information, we identified the constituents of concern and constituent mass fractions for each waste stream. As expected, some of the waste streams had very similar, or, in some cases identical, constituents. For example, ignitable paint wastes and ignitable waste both contained toluene and methyl ethyl ketone. Including each of these waste streams in the risk assessment increases the complexity of the analysis but provides very little additional information on risk. In order to reduce the complexity of the analysis, we combined waste streams rather than including individual waste streams in cases where several of the waste streams have very similar characteristics. Similar waste streams were combined, using a weighted average based on total waste quantity generated, to determine characteristics for the composite, or aggregate, waste streams.

We identified a total of five combined waste streams. The waste streams and associated characteristics are presented in Exhibit 4-15. The combined waste streams are: 1) spent solvents/ignitable wastes/ignitable paint wastes; 2) waste pesticides/pesticide washing and rinsing solutions; 3) heavy metal wastewater sludges/cyanide wastes/spent plating wastes/other reactive wastes; 4) photographic wastes/solutions and sludges with photo silver, and 5) waste ink with solvents or heavy metals/ink sludges with chromium or lead. These waste streams were found to contain similar constituents at similar concentrations, and therefore combining them will not result in an over- or under-estimation of risk, which can occur when dissimilar waste streams are combined.

For example, ignitable wastes, ignitable paint wastes, and spent non-halogenated solvents all contain waste solvents at similar concentrations, and, while the solvents are not exactly the same in all cases, their toxicities, mobilities, and degradation rates do not vary significantly, and thus they present similar risks. Also, while these wastes may contain different constituents in some cases (e.g. ignitable paint wastes may contain heavy metals in addition to solvents) the constituents that dominate risk are very similar for these wastes. If, however, these waste streams were aggregated with a pesticide waste stream containing a high-risk compound (e.g., lindane), the risk associated with this composite waste stream would probably be greatly over-estimated when compared to the real situation. Therefore, we avoided combining any but the most similar waste streams in this analysis.

EXHIBIT 4-13

SQG WASTES STORED IN TANKS RANKED ACCORDING TO TOTAL WASTE QUANTITY GENERATED AND TOTAL NUMBER OF TANKS

Composite Ranking	Waste Stream	Total Waste Quantity Ranking a/	Total Number of Tanks Ranking b/
1	Spent Solvents	1	1
2	Strong Acid or Alkaline Wastes	2	2
3	Photographic Wastes	3	3
4	Sludges or Solutions w/Photo Silver	4	5
5	Ignitable Paint Wastes	5	7
6	Filtration Residue from Dry Cleaning	9	4
7	Heavy Metal Wastewater Sludges	6	10
8	Waste Pesticides	7	12
9	Spent Plating Wastes	10	9
10	Ignitable Wastes	14	6
11	Other Reactive Wastes	8	13
12	Cyanide Wastes	11	11
13	Pesticide Washing & Rinsing Solution	15	8
14	Ink Sludge w/Chromium or Lead	13	15
15	Waste Ink with Solvents and Heavy Metal	13	15
16	Wastewater Wood Preservatives	15	16

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a/ Source: ICF Inc., et al., Economic Analysis of Resource Conservation and Recovery Act Regulations for Small Quantity Generators, report to the Office of Solid Waste, EPA, June 1985.

b/ Source: SQG Survey.

EXHIBIT 4-14

SQG WASTE STREAMS STORED IN ABOVE-GROUND AND UNDERGROUND TANKS a/

	Above-ground Tanks	Underground Tanks
Spent Solvents	X	X
Strong Acid or Alkaline Wastes	X	X
Photographic Wastes	X	X
Sludges or Solutions w/Photo Silver	X	None
Ignitable Paint Wastes	X	X
Filtration Residue from Dry Cleaning	X	X
Heavy Metal Wastewater Sludges	X	None
Waste Pesticides	X	X
Spent Plating Wastes	X	None
Ignitable Wastes	X	X
Other Reactive Wastes	X	X
Cyanide Wastes	X	None
Pesticide Washing & Rinsing Solutions	X	X
Ink Sludge w/Chromium or Lead	X	X
Waste Ink with Solvents and Heavy Metals	None	X
Wood Preservative Wastewater	X	X

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a/ Wastes are not ranked in this Exhibit.

EXHIBIT 4-15

REPRESENTATIVE SQG WASTE STREAMS

Waste Stream Description a/	Number of Facilities b/	Constituent Name c/d/	Constituent Mass Fraction c/	Relative Frequency of Occurrence b/e/
Spent Solvents/ Ignitable Paint Wastes/ Ignitable Wastes		Halogenated stream (category 1)		
		Chloroform	0.10	
		Carbontetrachloride	0.10	
	1967 (ag)	1,2-Dichlorobenzene	0.10	.204 (ag)
		1,1,1-Trichloroethane	0.10	.320 (ug)
	1286 (ug)	Trichloroethylene	0.10	
		Non-halogenated stream (category 2)		
		Toluene	0.10	
		Toluene diisocyanate	0.10	.204 (ag)
		Methyl ethyl ketone	0.10	.320 (ug)
		Benzene	0.10	
		Xylene	0.10	
		Acetaldehyde	0.10	
Strong Acid or Alkaline Wastes	1358 (ag)	Lead	0.0005	.282 (ag)
		Hydrochloric acid	0.05	.147 (ug)
	295 (ug)	(or) Sodium hydroxide	0.05	
Photographic Wastes/ Solutions or Sludges with Photo Silver	820 (ag)	Methanol	0.14	.170 (ag)
		Acetone	0.14	
	56 (ug)	Phenol	0.09	.028 (ug)
		Cyanide	0.00000057	
Filtration Residues from Dry Cleaning	63 (ag)	Tetrachloroethylene	0.53	.013 (ag)
	31 (ug)			.015 (ug)
Heavy Metal Wastewater Sludges Spent Plating Wastes/ Cyanide Wastes/ Other Reactive Wastes	305 (ag)	Chromium (VI)	0.0110	.064 (ag)
		Copper	0.0051	
		Cadmium	0.0031	
		Lead	0.00018	
		Nickel	0.0105	
		Cyanide	0.0093	

EXHIBIT 4-15 (continued)

REPRESENTATIVE SQG WASTE STREAMS

Waste Stream Description a/	Number of Facilities b/	Constituent Name c/d/	Constituent Mass Fraction c/	Relative Frequency of Occurrence b/e/
Waste Pesticides/ Pesticide Washing and Rinsing Solutions	160 (ag) 180 (ug)	Lindane (category 1)	0.01	.017 (ag) .045 (ug)
		Aldicarb (category 2)	0.01	.017 (ag) .045 (ug)
Wood Preservative Wastewaters	16 (ag) 4 (ug)	Acenaphthene Chrysene Pentachlorophenol	0.00030 0.00010 0.00078	.028 (ag) .002 (ug)
Waste Ink with Solvents or Heavy Metals/ Ink Sludge with Chromium or Lead	158 (ug)	Chromium VI) Lead Toluene	0.00061 0.00032 0.00010	.079 (ug)

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a/ In order to simplify the analysis, similar waste streams were combined in some cases.

b/ Numbers represent the weighted number of primary SIC-code facilities reported in the OSW SQG survey to store the given waste stream in tanks according to the tank type (i.e., underground (ug) or above-ground (ag)) at the facility.

c/ Constituents and mass fractions were identified from SQG Economic Analysis Report (OSW-ICF/DPRA/PRA); For waste streams whose characteristics were not identified in this report, professional judgement was used to identify constituents and mass fractions.

d/ Categories were identified using professional judgement.

e/ Assumes that selected wastes represent 100 percent of all wastes handled in SQG tanks.

Finally, after identifying the important SQG waste streams that are stored in above-ground and underground tanks, we assigned characteristics to these waste streams from data contained in the economic analysis report. We then combined similar waste streams and calculated the relative frequency of occurrence for each waste stream. We obtained the total number of above-ground and underground SQG tanks, and divided the number of tanks for each waste stream by the total number of SQG storage tanks for that tank type (above-ground or underground). For example, DPRA, Inc. identified 4,809 above-ground SQG storage tanks, of which 1,358 are used to store strong acid or alkaline wastes. Thus, the relative frequency of occurrence for that waste stream in above-ground tanks is 1,358/4,809, or 28.2 percent. These frequencies represent the waste stream weights assigned to the two model SQG tanks.

Exhibit 4-15 also presents waste stream characteristics and frequency of occurrence for each of the identified SQG waste streams. We identified a total of eight types of waste streams, five of which are combined waste streams. Of note is that in some cases it was necessary to supplement the available data with our judgement as to what was contained in a particular waste stream. For example, information on waste pesticides and pesticide washing and rinsing solutions did not specify which pesticides are disposed of more frequently than others. Since constituents must be specified in order to estimate risk, we included two pesticide waste streams; one containing a highly toxic, highly persistent, but relatively non-mobile pesticide, such as lindane; and one containing a more mobile but less toxic pesticide, such as aldicarb. These two waste streams represent a large variety of pesticides currently in use. We assumed that each of these waste stream categories have equal frequencies of occurrence.

A similar problem arose in the case of spent solvent wastes, where a total of 11 solvents may commonly be found. The toxicities, mobilities, and degradation rates of these substances vary considerably, and it is also unlikely that all would be found in any single waste stream. Thus, if all of these constituents are included in all situations, the risk associated with this waste stream may be significantly over-estimated as a result of the inclusion of high-risk compounds such as carbon tetrachloride that would probably not always be present. Therefore, we have divided spent solvents into two waste stream categories, halogenated and non-halogenated solvents, with equal frequencies of occurrence, as is illustrated in Exhibit 4-15.

These assumptions made with respect to waste stream constituents and constituents' concentrations have a significant impact on the results of the risk analysis. However, we believe that the waste streams selected are reasonably representative of the SQG waste streams most commonly stored in tanks, and thus are useful in deriving representative risk distributions for these tanks.

4.3.2 RCRA-Permitted Storage Tank Waste Streams

We used data from several sources to identify waste streams that are generated in the greatest quantity and are stored in RCRA-permitted tanks.

Our selection process was based on ranking the waste streams according to available information on total waste stream quantity generated, total quantity handled in tanks, number of facilities handling a waste stream, and the chronic toxicity of the waste streams' constituents of concern. The data sources that we used included the following:

- The RCRA Risk-Cost Analysis Model Waste Stream Data Base, (July 1984) (referred to in this analysis as the W-E-T Model data base). This data base contains information on 267 hazardous waste streams collected from 106 references. It contains data on waste quantity generated, number of generators, and waste stream characteristics, but does not contain specific information on the processes used to treat, store, and/or dispose of the included waste streams.

- The National Survey of Hazardous Waste Generators and Treatment, Storage, and Disposal Facilities Regulated Under RCRA in 1981, (April 1984) (referred to in this analysis as the OSW RIA Mail Survey). This survey, while lacking specific information on waste stream characteristics is a more comprehensive data source in that it identifies waste management practices, and the waste streams managed in these practices, at RCRA Part A-permitted facilities as of 1981. Waste streams in the survey are identified by EPA waste code, and are characterized by treatment, storage, and/or disposal method.

- Appendices for Supporting Documentation for the RCRA Incinerator Regulations, 40 CFR 264 Subpart D - Incinerators, (July 1984) (referred to in this analysis as the Incinerator Data Base). This data base contains information on characteristics for unspecified RCRA waste streams (e.g., D001).

- Documentation for the Development of Toxicity and Volume Scores for the Purpose of Scheduling Hazardous Wastes, (March 1985) (referred to in this analysis as the ENVIRON Toxicity-Volume Report). This data source contains information on chronic toxicity for more than 100 hazardous chemicals.

The W-E-T model data base served two major purposes in this analysis: (1) it provided a great deal of information on specific waste stream characteristics; and (2) it represented a "master list" of the largest quantity hazardous waste streams generated in the U.S., which was useful for comparison purposes to the more tank-specific information included in other data sources.

In our selection process, we first compiled five lists of relevant waste streams by identifying the largest quantity of waste streams handled in tanks or disposal processes. Using information from the OSW Mail Survey, we identified and listed the top 50 waste streams (in terms of total quantity handled) for each of the following waste categories:

- stored in tanks;
- treated in tanks;
- treated in other processes;
- disposed of by injection; and
- disposed of by incineration.[12]

We eliminated wastes that are most commonly landfilled, treated or disposed of in surface impoundments, and handled in land treatment systems and waste piles. A further reduction in the total number of wastes considered was made by eliminating solid or gaseous waste streams (e.g., heavy metal dust, industrial gases, etc.).

These five lists, each containing 50 ranked waste streams, provided tank-specific information on storage tank waste streams, and, along with the W-E-T Model "master list", allowed for extensive cross-referencing in identifying the waste streams most commonly handled in tanks. However, characteristics for EPA D waste codes, which were ranked highly in nearly all the above categories, were not included in either the OSW or W-E-T Model data bases. The Incinerator Data Base was therefore used to characterize D wastes (i.e., to identify the constituents of concern for D wastes).[13]

Finally, we evaluated the waste streams in terms of the toxicity of the associated constituents. We assigned toxicity scores on a relative scale based on available information and used the most toxic constituent in each waste stream as an overall indicator of waste toxicity.[14]. These toxicity scores were used to supplement waste stream quantity and tank-specific information in the final selection process.

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[12] For the purposes of the analysis it was assumed that wastes disposed of by injection, incineration, and other processes would be handled in tanks at some point in the treatment/storage/disposal process. Consequently, we included these waste streams in our analysis.

[13] Wastes that are to be incinerated must have relatively high contents of flammable organic liquids. Consequently, we identified constituents of concern such as toluene, acetone, and methanol for D wastes. However, D wastes may contain a wide variety of substances, some of which may pose very little chronic risk. Because we assigned relatively high-risk constituents to D wastes, our analysis likely over-estimates the risks attributable to waste streams D001, D002, and D003.

[14] Toxicity values were obtained from Documentaion for the Development of Toxicity and Volume Scores for the Purpose of Scheduling Hazardous Waste, report to the Office of Solid Waste, EPA, by Environ Corp., March 1985.

Exhibit 4-16 presents information on 21 waste streams that we identified as the most representative of the wastes commonly handled in RCRA-permitted storage tanks. We used total quantity handled in tanks as our primary selection criterion. In cases where several wastes were handled in similar quantities, we chose the waste containing the most toxic constituents. The list includes aqueous waste streams containing heavy metals and cyanides, spent solvents, and concentrated U wastes such as phenol and dichloromethane.

Once representative waste streams were selected, it was necessary to distribute them over the population of model storage tanks considered in the analysis. In order to accomplish this, we used the dominant RCRA characteristic (ignitability, corrosivity, reactivity, EP toxicity, or toxicity) assigned by EPA for each waste code. We then used data from the OSW Hazardous Waste Tank RIA Survey (part of OSW Mail Survey) on the percentages of above-ground, in-ground, and underground tanks storing each type of RCRA characteristic waste to determine the percentage of each tank type storing a particular waste stream. Of note is that approximately 50 percent of the facilities surveyed in the RIA reported that their tanks were used to store waste mixtures, and, therefore, we developed five waste streams (X500 through X504 in Exhibit 4-16) to represent these mixtures. Based on information in the RIA data base, we also determined the percentage of above-ground, in-ground, and underground tanks storing each waste stream.

4.3.4 Accumulation Tank Waste Streams

Sources of data for hazardous waste accumulation tanks were neither as comprehensive nor as plentiful as they were for hazardous waste treatment and storage tanks (RCRA-permitted tanks) or for small quantity generator (SQG) tanks. However, by cross-referencing between the available data sources, we selected a reasonably representative sample of waste streams that are handled in accumulation tanks. We used the following data sources:

- RCRA Risk-Cost Analysis Model data base (W-E-T Model data base). This data base contains detailed information on 264 hazardous waste streams at the generator stage. It is very comprehensive but does not contain information on storage and disposal for the included waste streams; thus, no direct evidence linking a particular waste stream with hazardous waste tanks is available in these data.

- EPA Hazardous Waste Generator Survey. This survey contains information on waste streams (waste stream ID code and frequency reported (number of facilities reporting a particular waste stream)) and also contains information on whether accumulation tanks are used at each of the surveyed facilities. Thus, while there is no direct link between

EXHIBIT 4-16

REPRESENTATIVE WASTE STREAMS FOR RCRA-PERMITTED STORAGE TANKS a/

Waste Stream Category	EPA Waste Code b/	Constituent Name c/	Constituent Mass Fraction c/	Dominant RCRA Characteristics d/	Percentage of Tanks Storing Waste Stream e/
Corrosive, NOS	D002	Chloride	0.05	Corrosive	0.072
		Methanol	0.0432		
		Copper	0.0005		
		Toluene	0.0381		
Reactive, NOS	D003	Acetone	0.0894	Reactive	0.004
		Toluene	0.0838		
		Cyanide	0.001		
		2,4-Dinitrotoluene	0.161		
Acrylonitrile Wastes	K011	Acetonitrile	0.006	Reactive	0.002
		Cyanide	0.003		
		Acrylonitrile	0.0004		
EP Chromium	D007	Chromium	0.0005	EP Toxic	0.0018
Spent Halogenated Solvents	F001	Chloroform	0.10	Toxic	0.053
		Carbon Tectrachloride	0.10		
		1,2-Dichlorobenzene	0.10		
		1,1,1-Trichloroethane	0.10		
		Trichloroethylene	0.10		
Spent Non-halogenated Solvents	F003	Toluene	0.10	Ignitable	0.110
		Toluene Diisocyanate	0.10		
		Methyl Ethyl Ketone	0.10		
		Benzene	0.10		
		Acetaldehyde	0.10		
		Xylene	0.10		
Ignitable, NOS	D001	Methanol	0.0941	Ignitable	0.148
		Toluene	0.0695		
		Acetone	0.1552		
		Xylene	0.1942		
		Benzene	0.1176		
		Methyl Ethyl Ketone	0.1401		
Petroleum Refining Wastes	K048	Chromium	0.000004	Toxic	0.017
		Lead	0.000026		

EXHIBIT 4-16 (Continued)

REPRESENTATIVE WASTE STREAMS FOR RCRA-PERMITTED STORAGE TANKS a/

Waste Stream Category	EPA Waste Code b/	Constituent Name c/	Constituent Mass Fraction c/	Dominant RCRA Characteristics d/	Percentage of Tanks Storing Waste Stream e/
Spent Pickle Liquor	K062	Chromium	0.00001	Corrosive	0.010
		Lead	0.0001		
Electroplating Wastes	F007	Cadmium	0.001	Reactive	0.0001
		Copper	0.00014		
		Cyanide	0.000075		
		Chromium	0.00017		
		Nickel	0.0015		
Non-Cyanide Electroplating Wastes	F006	Copper	0.0018	Toxic	0.011
		Chromium	0.00068		
		Cadmium	0.00035		
		Lead	0.0004		
		Nickle	0.003365		
EP Arsenic	D004	Arsenic	0.0005	EP Toxic	0.0001
Dichloromethane	U080	Dichloromethane	1.000	Toxic	0.0014
Phenol	U188	Phenol	1.000	Toxic	0.025
Thallium Sulfate	P115	Thallium Sulfate	0.01	Toxic	0.0005
Chlorinated Pesticide Production Wastes	X907	Hexachlenobutadiene	0.10	Toxic	0.0056
		Hexachlorocyclopentadiene	0.10		
		Hexachlorobenzene	0.10		
		Chloroform	0.10		
		Carbon Tetrachloride	0.10		
Ignitable Waste Mixture	X500	Toluene	0.0894	Ignitable	0.171
		Toluene Diisocyanate	0.10		
		Methyl Ethyl Ketone	0.123		
		Benzene	0.110		
		Acetaldehyde	0.10		
		Acetone	0.155		
Corrosive Waste Mixture	X501	Chloride	0.05	Corrosive	0.118
		Methanol	0.043		
		Toluene	0.038		
		Chromium	0.00001		
		Lead	0.0001		

EXHIBIT 4-16 (Continued)

REPRESENTATIVE WASTE STREAMS FOR RCRA-PERMITTED STORAGE TANKS a/

Waste Stream Category	EPA Waste Code b/	Constituent Name c/	Constituent Mass Fraction c/	Dominant RCRA Characteristics d/	Percentage of Tanks Storing Waste Stream e/
Reactive Waste Mixture	X502	Cyanide	0.00733	Reactive	0.048
		Toluene	0.0838		
		2,4-Dinitrotoluene	0.1610		
		Acetonitrile	0.006		
		Acrylonitrile	0.0004		
EP Toxic Waste Mixture	X503	Chromium	0.0005	EP Toxic	0.076
		Arsenic	0.0005		
Toxic Waste Mixture	X504	Chloroform	0.10	Toxic	0.124
		Carbon Tetrachloride	0.10		
		Trichloroethylene	0.10		
		1,1,1-Trichloroethane	0.10		
		Hexachlorobenzene	0.10		
		Tetrachloroethylene	0.10		

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a/ For both the model above-ground storage tanks, we assumed they handle all the listed waste streams. The carbon steel, underground tanks store all listed wastes, except for D003, K011, D007, F007, and D004. The fiberglass reinforced plastic tanks store K062, D007, K048, F006, P115 and X504. The stainless steel underground tanks store all wastes except for D003, K011, D007, F007 and D004. The concrete in-ground tanks store K048, F006, P115, and X504. The carbon steel in-ground tanks store K062, D007, K048, F006, D004, P115 and D002.

b/ Waste codes are combined in some cases for similar waste streams (e.g., F003 is used to represent F003-F005).

c/ Constituents and mass fractions taken from W-E-T Model data base.

d/ Dominant RCRA characteristics identified based on EPA waste code information and professional judgement.

e/ Calculated based on dominant RCRA characteristics; assumes that selected wastes represent 100 percent of all wastes stored in RCRA-permitted storage tanks.

waste streams and accumulation tanks in this data base, we assume that for facilities having accumulation tanks, the waste streams generated by these facilities most frequently are most likely to be handled in accumulation tanks.

Using the above mentioned data bases we compiled three lists: a list of the 50 waste streams generated in the greatest quantity (from the W-E-T Model data base); a list of the most frequently reported waste streams for facilities handling waste under the 90-day exclusion rule (from the Hazardous Waste Generator Survey); and a list of the most frequently reported waste streams for facilities handling waste in accumulation tanks.

These lists were cross-referenced, with most weight given to wastes reported at facilities having accumulation tanks. For the most part, there was generally good agreement between the three lists, although some wastes that ranked high on the W-E-T Model list were not reported by hazardous waste generators included in the Generator Survey. This probably indicates that some blending of wastes occurs at generator facilities before on-site or off-site disposal.

Based on a cross-reference of the three lists, a total of 12 waste streams considered to be representative of those handled in accumulation tanks were selected according to their rankings on each of the three lists. We excluded wastes not represented on all three lists, and established a cut-off for wastes based on frequency of reporting. These selected wastes were then distributed over the population of model accumulation tanks according to the frequencies reported for the waste streams from the Hazardous Waste Generator Survey.

The 12 waste streams that we selected to represent wastes stored in accumulation tanks are presented in Exhibit 4-17. For the most part, these waste streams are very similar to the representative waste streams identified in our analysis for RCRA-permitted storage tanks. However, as expected, more EPA U code waste streams were identified for accumulation tanks than for storage tanks. In general, accumulation tanks are more closely associated with hazardous waste generators than with treatment, storage, and disposal (TSD) facilities and thus one would expect to find more "generator" wastes reported for accumulation tanks.

Accumulation tank waste stream information is not as reliable as the waste stream data compiled for SQG and RCRA-permitted storage tanks in this analysis, due to lack of data that would allow for the direct identification of wastes most commonly handled in accumulation tanks. Therefore, the results of our risk analysis are significantly more uncertain for these tanks. Also, we had no data that would allow us to determine the percentages of above-ground, in-ground, and underground tanks storing these waste streams and used professional judgement to compile these percentages.

EXHIBIT 4-17

REPRESENTATIVE ACCUMULATION TANK WASTE STREAMS a/

Waste Stream Description	Waste Code b/	Constituent Name c/	Constituent Mass Fraction c/	Percentage of Tanks Storing Waste Stream d/
Corrosive, NOS e/	D002	Chloride	0.05	0.225
		Methanol	0.0432	
		Copper	0.0005	
		Toluene	0.0381	
Ignitable, NOS	D001	Methanol	0.0941	0.190
		Toluene	0.0695	
		Acetone	0.1552	
		Xylene	0.1942	
		Benzene	0.1176	
		Methyl ethyl ketone	0.1401	
EP Chromium f/	D007	Chromium	0.0005	0.075
EP Lead	D008	Lead	0.0005	0.054
Spent Pickle Liquor	K062	Chromium	0.000010	0.036
		Lead	0.000100	
Spent Non-Halogenated Solvents	F003	Benzene	0.10	0.138
		Toluene	0.10	
		Toluene diisocyanate	0.10	
		Methyl ethyl ketone	0.10	
		Xylene	0.10	
		Acetaldehyde	0.10	
Spent Halogenated Solvents	F001	Chloroform	0.10	0.142
		Carbon tetrachloride	0.10	
		1,2-Dichlorobenzene	0.10	
		1,1,1-Trichloroethane	0.10	
		Trichloroethylene	0.10	
1,1,1-Trichloroethane	U226	1,1,1-Trichloroethane	1.00	0.031
Electroplating Wastes	F007	Cadmium	0.00010	0.077
		Copper	0.00014	
		Cyanide	0.000075	
		Nickel	0.0015	

EXHIBIT 4-17 (continued)

REPRESENTATIVE ACCUMULATION TANK WASTE STREAMS a/

Waste Stream Description	Waste Code b/	Constituent Name c/	Constituent Mass Fraction c/	Percentage of Tanks Storing Waste Stream d/
Acrylonitrile	U009	Acrylonitrile	1.00	0.002
Dichloromethane	U080	Dichloromethane	1.00	0.022
Phenol	U188	Phenol	1.00	0.010

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a/ We assumed that both model above-ground accumulation tanks store all the listed waste streams. The carbon steel, underground tanks store all listed wastes except for D002, D007, D008, and F007. The fiberglass reinforced plastic tanks store D002 and K062. The stainless steel underground tanks store all wastes except for D007, D008, and F007. The concrete in-ground tanks store D007 and D008. The in-ground carbon steel tanks store D002, D007, D008 and K062.

b/ Waste codes combined in some cases for similar waste streams (e.g., F003 represents F003 through F005.

c/ Constituents and mass fractions obtained from W-E-T Model data base.

d/ Calculated from total quantities reported in Small Quantity Generator Survey; assumes that selected waste streams represent 100 percent of all wastes stored in accumulation tanks.

e/ NOS = not otherwise specified.

f/ EP = extraction procedure (waste has been determined to exceed the maximum contaminant level allowed under EPA's Extraction Procedure Toxicity Test).

4.3.5 Treatment Tank Waste Streams

Treatment tanks differ from the other tank categories included in the analysis in that a wide variety of treatment processes are carried out in tanks, and the type of waste treated in a particular tank is dependent upon the treatment process for which that tank is used. For example, an oxidation/reduction/precipitation system may be used to treat wastes containing heavy metals and cyanides, but will not treat waste streams containing high concentrations of organic solvents. Therefore, in order to simplify our analysis, we restricted our selection to two treatment processes that we believed were most representative of hazardous waste treatment tanks, and selected waste streams according to their compatibility with the two treatment processes. Data sources used in this selection process included:

- The Hazardous Waste Tank RIA Data Base, compiled by OSW in 1984; and

- The National Survey of Hazardous Waste Generators and Treatment, Storage, and Disposal Facilities Regulated Under RCRA in 1981, (April, 1984) and referred to in this analysis as the OSW Mail Survey.

The hazardous waste tank RIA data base was used to compile data on the most common hazardous waste treatment processes employing tanks, while the OSW Mail Survey provided a list of waste streams reported as most commonly treated in tanks.

Based on data from the RIA data base and the selection criteria described in Section 4.2, we selected oxidation/reduction/precipitation (ORP) and distillation as the two representative treatment technologies to be included in the risk analysis. Oxidation/reduction/precipitation is a relatively complex process that is used mainly to treat aqueous wastes containing heavy metals and cyanides, where as distillation is considerably less complex and is used to treat highly concentrated mixtures of organic solvents. Oxidation/reduction/precipitation was among the most highly ranked waste treatment technologies reported in the hazardous waste tank RIA data base, and was compatible with a large number of the highest-volume waste streams from the OSW mail survey. Distillation, while not as highly ranked in the RIA, was also compatible with a large number of waste streams from the OSW Mail Survey, and, because it is used to treat highly concentrated wastes, is not generally exempt under the RCRA wastewater treatment exemption. Both treatment processes are outlined in greater detail in Chapter 2 and in Section 4.2.

We selected 10 waste streams from the OSW Mail Survey list as compatible with ORP, and six waste streams as compatible with distillation. These waste streams are summarized in Exhibit 4-18. All 16 waste streams had previously been included in the analysis as representative RCRA-permitted storage tank waste streams, and, therefore, we used the constituents of concern and average concentrations for these wastes previously identified from the W-E-T model data base. The wastes were distributed over the model tank population based on the total quantity reported for each of the "waste treated in tanks" list from the OSW Mail Survey. The distribution was carried out according to the

EXHIBIT 4-18

REPRESENTATIVE WASTE STREAMS FOR SELECTED TREATMENT TECHNOLOGIES

Treatment Process	Waste Stream Description	Waste Code a/	Constituent Name b/	Constituent Mass Fraction b/	Percentage of Tanks Storing Waste Stream c/
Distillation	Spent Halogenated Solvents	F001	Chloroform	0.10	0.046
			Carbon tetrachloride	0.10	
			1,2-Dichlorobenzene	0.10	
			1,1,1-Trichloroethane	0.10	
			Trichloroethylene	0.10	
	Spent Non-Halogenated Solvents	F003	Benzene	0.10	0.107
			Toluene	0.10	
			Toluene diisocyanate	0.10	
			Methyl ethyl ketone	0.10	
			Xylene	0.10	
			Acetaldehyde	0.10	
	Chlorinated Pesticide Production Wastes	X907	Hexachlorobenzene	0.10	0.556
			Trichloroethylene	0.10	
			Chloroform	0.10	
			Hexachlorobutadiene	0.10	
			Carbon Tetrachloride	0.10	
			Hexachlorocyclopentadiene	0.10	
	Ignitable, NOS	D001	Methanol	0.0941	0.283
			Toluene	0.0695	
			Acetone	0.1552	
			Xylene	0.1942	
			Benzene	0.1176	
			Methyl ethyl ketone	0.1401	
	Dichloromethane	U080	Dichloromethane	1.00	0.004
	1,1,1-Trichloroethane	U226	1,1,1-Trichloroethane	1.00	0.004
Oxidation/Reduction Precipitation	Reactive, NOS	D003	Acetone	0.0894	0.294
			Toluene	0.838	
			Cyanide	0.0100	
			2,4-Dinitrotoluene	0.1601	
	Acrylonitrile Wastes	K011	Acetonitrile	0.006	0.031
			Cyanide	0.003	
			Acrylonitrile	0.0004	

EXHIBIT 4-18 (continued)

REPRESENTATIVE WASTE STREAMS FOR SELECTED TREATMENT TECHNOLOGIES

Treatment Technology	Waste Stream Description	Waste Code a/	Constituent Name b/	Constituent Mass Fraction b/	Percentage of Tanks Storing Waste Stream c/
Oxidation/Reduction Precipitation (continued)	EP Chromium	D007	Chromium	0.0005	0.152
	Petroleum Refining Sludges/Emulsions	K048	Chromium	0.000004	0.317
			Lead	0.000026	
	Spent Pickle Liquor	K062	Chromium	0.000010	0.024
			Lead	0.000100	
	Non-cyanide Electroplating Wastewaters	F006	Copper	0.0018	0.161
			Chromium	0.0068	
			Cadmium	0.00035	
			Lead	0.0004	
			Nickel	0.00365	
	Electroplating Wastewaters	F007	Cadmium	0.00010	0.018
			Copper	0.00014	
			Cyanide	0.000075	
			Chromium	0.00017	
			Nickel	0.0015	
	EP Arsenic	D004	Arsenic	0.0005	0.001
	Thallium Sulfate	P115	Thallium	0.10	0.0002
	EP Lead	D008	Lead	0.0005	0.0025

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a/ Waste codes combined in some cases for similar waste streams (e.g., F003 represents F003 through F005).

b/ Constituents and mass fractions from W-E-T Model data base.

c/ Assumes that selected wastes streams represent 100 percent of all wastes treated by that particular process.

treatment process assigned to a particular tank, rather than by tank type (e.g., above-ground, in-ground, or material). Consequently, all the model ORP treatment tanks have the same distribution of waste streams.

4.3.5 Assumptions and Limitations

Although a large number of data sources were identified and reviewed as part of the waste stream selection process, a lack of information about certain waste characteristics and tank management practices required that several assumptions be made. Major limitations resulting from these assumptions are as follows:

- Average waste stream characteristics (constituents of concern and concentrations for these constituents) identified from available data sources were used to represent waste streams in the analysis. In reality, waste characteristics may vary markedly from these average characteristics, and thus we may be over-estimating or under-estimating risks for the waste streams included in our analysis. In particular, the assumption regarding waste mixture characteristics adds significant uncertainty to the analysis.

- The waste streams selected for our analysis were assumed to represent 100 percent of the hazardous waste stored or treated in tanks. The selected waste streams represent the highest-volume chronically toxic wastes handled in tanks, but do not account for acutely toxic wastes or low-volume high toxicity wastes.

- In order to distribute waste streams over the population of model tanks, it was necessary to make assumptions regarding tank management practices. In general, we assumed that tanks were managed according to good engineering practices, and that wastes were compatible with tank materials. In reality, this would not always be the case, and tank-waste incompatibilities would lead to tank failures in some instances.

4.4 MAPPING TANK POPULATIONS INTO GENERIC HYDROGEOLOGIC SCENARIOS

The hydrogeologic setting underlying a tank influences the transport rate of contaminants through the ground water to potable wells downgradient of the tank. The setting is defined in terms of the unsaturated and saturated zones underlying the tank. Within the framework of the Tank Risk Analysis Model one representative unsaturated zone and nine different saturated zones are modeled.[15] In order to weight the risk estimates associated with each hydrogeologic scenario, we estimated the percentage of each tank category (i.e. SQG, storage, accumulation and treatment tank) population that is located within each scenario.[16] For example, we estimated that 15 percent of all storage tanks are located in a hydrogeologic setting with a vertical ground-water velocity of 10 meters per year. The derivation of these percentages is a three-step procedure as follows:

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[15] See Chapter 3, Transport, Exposure and Risk Models, for a description of the modeled unsaturated and saturated zones.

- Identify percentage of each ground-water scenario in each state;
- Identify percentage of tank category population in each state; and
- Calculate percentage of tank category population located in each ground-water scenario.

The methodologies and necessary data sources used to perform these three steps are described below. Section 4.4.4 then summarizes the assumptions we used to determine the percentages of the tank populations that we assigned to each ground-water scenario.

4.4.1 Ground-Water Scenarios Located Within Each State

The assignment of ground-water scenarios to each state was based on available information relating to the ground-water scenarios assigned to the widely used United States Geological Survey (USGS) regions. These regions are defined by similar features that influence the presence and availability of ground water (e.g., geologic conditions and the nature of recharge and discharge areas).[17] Assuming that the hydrogeologic scenarios identified to exist within a USGS region exist uniformly within the USGS region, and estimating the percentage of each state that is comprised of each USGS region, we estimated the percentage of ground-water settings within each state.

Exhibit 4-19 presents the USGS regions. Most USGS regions are contiguous areas. By visual inspection, we estimated the percent of each state covered by each USGS region. For example, approximately 20 percent and 80 percent of Massachusetts is comprised of USGS regions 7 and 9, respectively. Exhibit 4-20 presents the USGS regions within each state and the percent of the state that the USGS region comprises.

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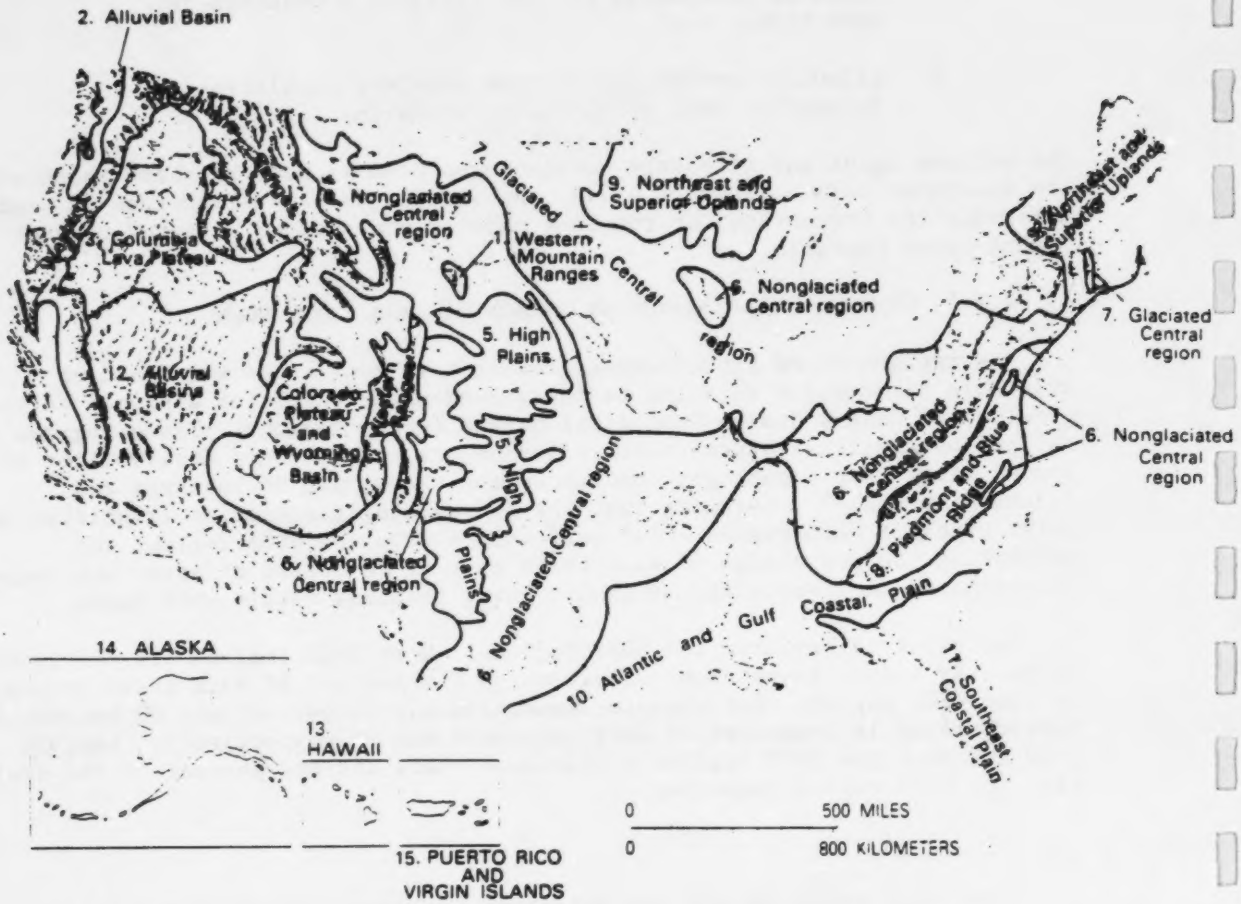
[16] For this study, we did not determine the distribution of hydrogelogic settings associated with each tank technology. Consequently, we assumed that that tank technologies associated with a particular category of tanks are distributed the same with respect to hydrogeologic settings. For example, the distribution for hydrogeologic settings that surround small quantity generator tanks, is the same for both above-ground and underground small quantity generator tanks.

[17] For a detailed description of the USGS regions see Heath, R.C., Groundwater Regions of the United States, USGS Water Supply Paper 2242, 1984.

EXHIBIT 4-19

USGS Regions a/


2. Alluvial Basin
3. Columbia Lava Plateau
2. Alluvial Basins
6. Nonglaciated Central region
1. Western Mountain Ranges
4. Colorado Plateau and Wyoming Basin
1. Western Mountain Ranges
5. High Plains
5. High Plains
6. Nonglaciated Central region
6. Nonglaciated Central region
7. Glaciated Central region
9. Northeast and Superior Uplands
6. Nonglaciated Central region
9. Northeast and Superior Uplands
7. Glaciated Central region
6. Nonglaciated Central region
6. Nonglaciated Central region
8. Piedmont and Blue Ridge
10. Atlantic and Gulf Coastal Plain
11. Southeast Coastal Plain
14. ALASKA
13. HAWAII
15. PUERTO RICO AND VIRGIN ISLANDS
0
500 MILES
0
800 KILOMETERS

a/ Source: Heath, R.C., 1984.

We obtained the generic ground-water scenarios representative of the USGS regions using information compiled from another study.[18] In order to make reasonable assignments of ground-water scenarios to each USGS region, this study divided each USGS region into a non-alluvial area and alluvial valley. All alluvial valleys were assigned ground-water scenarios C, D, G, and I, except for the southeast coastal plain. The alluvial valley within the southeast coastal plain has several swampy areas and was assigned ground-water scenarios A, B, C, D, E, F, G, and H. The assignment of ground-water scenarios to the non-alluvial areas within each USGS region was based on the characteristics of the region. Exhibit 4-21 presents the percent of non-alluvial areas and alluvial valleys assigned to each USGS region and the representative ground-water scenarios within each USGS region. We assumed that the ground-water scenarios are distributed uniformily within a USGS region.

We determined the percentage of each ground-water scenario within a state by multiplying the percentage of the state within each USGS region (Exhibit 4-20) by the percentage of the USGS region that is represented by the ground-water scenario (Exhibit 4-21). For example, four percent of Massachusetts is comprised of ground-water scenario C: .20 * (.68 * .167 + .32 * .25) + .80 * (.80 * .25 + .20 * .25). The percents used to derive the estimate that four percent of Massachusetts is comprised of ground-water scenario C are the following:

- 20 percent and 80 percent of the state are comprised of USGS regions 7 and 9, respectively (see Exhibit 4-20);
- 68 percent and 32 percent of USGS region 7 are non-alluvial and alluvial valley areas, respectively (see Exhibit 4-21);
- 16.7 percent and 25 percent of the non-alluvial and alluvial areas, respectively, in USGS region 7 are comprised of ground-water scenario C (see Exhibit 4-21);
- 80 percent and 20 percent of USGS region 9 are non-alluvial and alluvial valley areas, respectively, (see Exhibit 4-21).
- 25 percent and 25 percent of the non-alluvial and alluvial areas, respectively, in USGS region 9 are comprised of ground-water scenario C (see Exhibit 4-21).

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[18] JRB Associates, Comparative Risk Analysis for Ground-Water Sources, draft report, under EPA contract No. 658-01-6558, October 16, 1984.

EXHIBIT 4-20

PERCENT OF STATE WITHIN EACH USGS REGION

State	USGS Region 1	2	3	4	5	6	7	8	9	10	11
Alabama	0	0	0	0	0	40	0	5	0	50	5
Arkansas	0	0	0	0	0	55	0	0	0	45	0
Arizona	0	60	0	40	0	0	0	0	0	0	0
California	25	75	0	0	0	0	0	0	0	0	0
Colorado	25	5	0	30	15	25	0	0	0	0	0
Connecticut	0	0	0	0	0	0	30	0	70	0	0
Delaware	0	0	0	0	0	0	0	0	0	100	0
Florida	0	0	0	0	0	0	0	0	0	5	95
Georgia	0	0	0	0	0	15	0	30	0	25	30
Iowa	0	0	0	0	0	5	95	0	0	0	0
Idaho	75	10	15	0	0	0	0	0	0	0	0
Illinois	0	0	0	0	0	10	90	0	0	0	0
Indiana	0	0	0	0	0	15	0	85	0	0	0
Kansas	0	0	0	0	30	55	15	0	0	0	0
Kentucky	0	0	0	0	0	90	0	0	0	10	0
Louisiana	0	0	0	0	0	0	0	0	0	100	0
Massachusetts	0	0	0	0	0	0	20	0	80	0	0
Maryland	0	0	0	0	0	10	0	50	0	40	0
Maine	0	0	0	0	0	0	0	0	100	0	0
Michigan	0	0	0	0	0	0	80	0	20	0	0
Minnesota	0	0	0	0	0	0	50	0	50	0	0
Missouri	0	0	0	0	0	50	50	0	0	0	0
Mississippi	0	0	0	0	0	0	0	0	0	100	0
Montana	25	0	0	0	0	60	15	0	0	0	0
North Carolina	0	0	0	0	0	10	0	55	0	35	0
North Dakota	0	0	0	0	0	20	80	0	0	0	0
Nebraska	0	0	0	0	65	15	20	0	0	0	0
New Hampshire	0	0	0	0	0	0	0	0	100	0	0
New Jersey	0	0	0	0	0	20	15	0	15	50	0
New Mexico	10	0	0	15	10	65	0	0	0	0	0
Nevada	0	90	10	0	0	0	0	0	0	0	0
New York	0	0	0	0	0	0	50	0	50	0	0
Ohio	0	0	0	0	0	40	60	0	0	0	0
Oklahoma	0	0	0	0	10	90	0	0	0	0	0
Oregon	40	0	60	0	0	0	0	0	0	0	0
Pennsylvania	0	0	0	0	0	60	30	10	0	0	0
Rhode Island	0	0	0	0	0	0	0	0	100	0	0
South Carolina	0	0	0	0	0	0	0	50	0	50	0
South Dakota	10	0	0	0	5	40	45	0	0	0	0
Tennessee	0	0	0	0	0	70	0	0	0	30	0
Texas	0	10	0	0	10	50	0	0	0	30	0
Utah	10	40	0	50	0	0	0	0	0	0	0
Virginia	0	0	0	0	0	55	0	25	0	20	0
Vermont	0	0	0	0	0	0	0	0	100	0	0
Washington	50	15	35	0	0	0	0	0	0	0	0
Wisconsin	0	0	0	0	0	10	60	0	30	0	0
West Virginia	0	0	0	0	0	100	0	0	0	0	0
Wyoming	35	0	0	30	5	30	0	0	0	0	0

a/ Source: ICF estimates.

EXHIBIT 4-21

DISTRIBUTION OF GROUND-WATER SCENARIOS WITHIN USGS REGIONS a/

USGS Regions	Percent Land Area		Percent of Representative Ground-Water Scenarios b/								
			A	B	C	D	E	F	G	H	I
1. Western Mountain Ranges	Non-Alluvial Area	84	0.0	25.0	25.0	0.0	0.0	25.0	0.0	25.0	0.0
	Alluvial Valley	16	0.0	0.0	25.0	25.0	0.0	0.0	25.0	0.0	25.0
2. Alluvial Basins	Non-Alluvial Area	92	12.5	12.5	12.5	12.5	0.0	12.5	12.5	12.5	12.5
	Alluvial Valley	8	0.0	0.0	25.0	25.0	0.0	0.0	25.0	0.0	25.0
3. Columbia Lava Plateau	Non-Alluvial Area	82	0.0	20.0	20.0	20.0	0.0	0.0	20.0	20.0	0.0
	Alluvial Valley	18	0.0	0.0	25.0	25.0	0.0	0.0	25.0	0.0	25.0
4. Colorado Plateau and Wyoming Basin	Non-Alluvial Area	85	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
	Alluvial Valley	15	0.0	0.0	25.0	25.0	0.0	0.0	25.0	0.0	25.0
5. High Plains	Non-Alluvial Area	84	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
	Alluvial Valley	16	0.0	0.0	25.0	25.0	0.0	0.0	25.0	0.0	25.0
6. Non-Glaciated Central	Non-Alluvial Area	81	20.0	20.0	0.0	0.0	20.0	20.0	0.0	0.0	20.0
	Alluvial Valley	19	0.0	0.0	25.0	25.0	0.0	0.0	25.0	0.0	25.0
7. Glaciated Central	Non-Alluvial Area	68	16.7	16.7	16.7	0.0	0.0	16.7	16.7	0.0	16.7
	Alluvial Valley	32	0.0	0.0	25.0	25.0	0.0	0.0	25.0	0.0	25.0
8. Piedmont and Blue Ridge	Non-Alluvial Area	85	33.3	33.3	0.0	0.0	0.0	33.3	0.0	0.0	0.0
	Alluvial Valley	15	0.0	0.0	25.0	25.0	0.0	0.0	25.0	0.0	25.0
9. Northeast and Superior Uplands	Non-Alluvial Area	80	0.0	25.0	25.0	0.0	0.0	25.0	25.0	0.0	0.0
	Alluvial Valley	20	0.0	0.0	25.0	25.0	0.0	0.0	25.0	0.0	25.0
10. Atlantic and Gulf Coastal Plain	Non-Alluvial Area	76	14.3	14.3	14.3	0.0	0.0	14.3	14.3	14.3	14.3
	Alluvial Valley	24	0.0	0.0	25.0	25.0	0.0	0.0	25.0	0.0	25.0
11. Southeast Coastal Plain	Non-Alluvial Area	80	0.0	20.0	20.0	20.0	0.0	20.0	0.0	0.0	20.0
	Alluvial Valley	20	0.0	0.0	25.0	25.0	0.0	0.0	25.0	0.0	25.0

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a/ Source: JRB Associates, Comparative Risk Analysis for Ground-water Sources, draft report, EPA contract No. 658-01-6558, October 16, 1984, p. 1-9.

b/ Generic hydrogeologic settings assigned to USGS regions are assumed to be uniformily distributed within the USGS region.

Exhibit 4-22 presents the percent of the state that is comprised of each of the ground-water scenarios.

4.4.2 Tank Category Population Within Each State

Based on a variety of data sources, we estimated the percentages of each tank category (i.e., treatment, storage, small quantity generator and accumulation tank) population within each state. We obtained the distribution of treatment and storage tanks from Part A Permit Application data. Because we had insufficient information on the location of accumulation tanks we assumed that the distribution for accumulation tanks was equivalent to the distribution for storage tanks. Exhibit 4-23 presents the distribution of the tank categories throughout the contiguous United States.

We based the distribution of small quantity generator tanks on the distribution of waste associated with small quantity generators. We used information compiled for a previous study on small quantity genertors.[19] For this previous study, the Small Quantity Generator Survey and County Business Patterns data from 1982 were used to determine the geographical distribution of SQG wastes. Because some SQG wastes are not stored in tanks, according to the SQG survey, we eliminated several waste streams from the list of generated wastes.[20] We assumed that the percent of SQG tanks located within each state was distributed in the same way that the quantity of wastes are distributed. Exhibit 4-24 presents the distribution of SQG tanks among the states.

4.4.3 Distribution of Tank Categories Within Each Ground-water Scenario

The calculation of the percentage of each tank category population assigned to each ground-water scenario is a straightforward procedure. For each tank category and ground-water scenario, we multiplied the percentage of the tank population located in each state by the percentage of the state that is comprised of the ground-water scenario. For each scenario, the products were summed across all states to obtain the percentage of the tank category population that is represented by the ground-water scenario. Exhibit 4-24 presents the distribution of the tank categories among the ground-water scenarios. We used these percentages to weight the risk estimates in order to obtain distributions of risk estimates.[21]

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[19] See ICF Incorporated, et al., Economic Analysis of Resource Conservation and Recovery Act Regulations for Small Quantity Generators, prepared for the Office of Solid Waste, EPA, June 1985.

[20] The following wastes were eliminated: arsenic wastes, heavy metal dust, heavy metal waste materials, paint waste with heavy metals, solvent still bottoms, waste formaldehyde, and wastes with ammonia.

[21] See Section 4.1, Distributions of Risk Estimates, for a description of the use of the percentages in calculating national risk estimates.

EXHIBIT 4-22

PERCENT OF STATE REPRESENTED BY EACH GROUND-WATER SCENARIO

	Ground-water Scenario								
STATE	A	B	C	D	E	F	G	H	I
Alabama	13.5	14.3	11.4	6.0	6.6	14.3	10.6	5.6	17.8
Arkansas	13.8	13.8	10.2	5.3	8.9	13.8	10.2	4.9	19.1
Arizona	10.7	10.7	13.4	13.4	3.8	10.7	13.4	10.7	13.4
California	8.6	13.9	16.4	11.1	0.0	13.9	11.1	13.9	11.1
Colorado	8.9	14.1	14.1	8.8	8.3	14.1	8.8	10.1	12.9
Connecticut	3.4	17.4	23.3	5.9	0.0	17.4	23.3	0.0	9.3
Delaware	10.9	10.9	16.9	6.0	0.0	10.9	16.9	10.9	16.9
Florida	2.9	18.1	18.4	17.9	2.4	18.1	3.2	2.9	16.0
Georgia	14.4	19.2	11.6	8.9	3.2	19.2	6.8	3.5	13.3
Iowa	11.2	11.2	19.0	8.3	0.5	11.2	19.0	0.5	19.0
Idaho	1.2	19.4	23.2	7.5	0.0	16.9	7.5	19.4	5.0
Illinois	11.8	11.8	17.9	7.7	1.6	11.8	17.9	0.0	19.5
Indiana	12.1	12.1	17.1	7.5	2.4	12.1	17.1	0.0	19.6
Kansas	13.4	13.4	9.5	7.8	11.7	13.4	9.5	2.8	18.4
Kentucky	15.7	15.7	6.0	4.9	14.6	15.7	6.0	1.1	20.5
Lousiana	10.9	10.9	16.9	6.0	0.0	10.9	16.9	10.9	16.9
Massachusetts	2.3	18.3	23.9	5.6	0.0	18.3	23.9	0.0	7.9
Maryland	20.1	20.1	9.1	4.8	1.6	20.1	9.1	4.3	10.7
Maine	0.0	20.0	25.0	5.0	0.0	20.0	25.0	0.0	5.0
Michigan	9.1	13.1	20.5	7.4	0.0	13.1	20.5	0.0	16.5
Minnesota	5.7	15.7	22.2	6.5	0.0	15.7	22.2	0.0	12.2
Missouri	13.8	13.8	12.0	6.4	8.1	13.8	12.0	0.0	20.1
Mississippi	10.9	10.9	16.9	6.0	0.0	10.9	16.9	10.9	16.9
Montana	11.4	16.7	12.0	5.0	9.7	16.7	6.8	5.3	16.5
North Carolina	21.0	21.0	8.4	4.6	1.6	21.0	8.4	3.8	10.1
North Dakota	12.3	12.3	16.4	7.4	3.2	12.3	16.4	0.0	19.7
Nebraska	10.8	10.8	13.2	11.0	8.5	10.8	13.2	6.1	15.7
New Hampshire	0.0	20.0	25.0	5.0	0.0	20.0	25.0	0.0	5.0
New Jersey	10.4	13.4	16.0	5.9	3.2	13.4	16.0	5.4	16.3
New Mexico	13.6	15.7	8.1	6.0	13.6	15.7	6.0	3.5	18.1
Nevada	10.4	12.0	14.2	14.2	0.0	10.4	14.2	12.0	12.6
New York	5.7	15.7	22.2	6.5	0.0	15.7	22.2	0.0	12.2
Ohio	13.3	13.3	13.5	6.7	6.5	13.3	13.5	0.0	20.0
Oklahoma	15.5	15.5	5.6	5.6	15.5	15.5	5.6	0.9	20.2
Oregon	0.0	18.2	22.5	14.1	0.0	8.4	14.1	18.2	4.3
Pennsylvania	16.0	16.0	9.0	5.6	9.7	16.0	9.0	0.0	18.7
Rhode Island	0.0	20.0	25.0	5.0	0.0	20.0	25.0	0.0	5.0
South Carolina	19.6	19.6	10.3	4.9	0.0	19.6	10.3	5.4	10.3
South Dakota	12.0	14.1	13.8	6.6	6.9	14.1	11.7	2.6	18.1
Tennesse	14.6	14.6	8.4	5.1	11.3	14.6	8.4	3.3	19.7
Texas	13.4	13.4	10.1	6.9	9.0	13.4	10.1	5.3	18.2
Utah	9.3	11.4	14.5	12.4	4.7	11.4	12.4	11.4	12.4
Virginia	18.2	18.2	6.9	4.8	8.9	18.2	6.9	2.2	15.8
Vermont	0.0	20.0	25.0	5.0	0.0	20.0	25.0	0.0	5.0
Washington	1.7	18.0	21.8	11.3	0.0	12.2	11.3	18.0	5.6
Wisconsin	8.4	14.4	19.6	6.8	1.6	14.4	19.6	0.0	15.2
West Virginia	16.2	16.2	4.7	4.7	16.2	16.2	4.7	0.0	21.0
Wyoming	8.2	15.5	14.8	7.5	8.2	15.5	7.5	10.7	12.3

EXHIBIT 4-23

DISTRIBUTION OF TANK CATEGORIES WITHIN EACH STATE

State	Treatment a/ Tanks	Storage a/ Tanks	SQG b/ Tanks	Accumulation c/ Tanks
Alabama	0.0153	0.1350	0.0131	0.0135
Arkansas	0.0084	0.0056	0.0078	0.0056
Arizona	0.0091	0.0088	0.0085	0.0088
California	0.0745	0.0776	0.1113	0.0776
Colorado	0.0076	0.0088	0.0119	0.0088
Connecticut	0.0668	0.0423	0.0234	0.0423
Delaware	0.0035	0.0038	0.0020	0.0038
Florida	0.0223	0.0139	0.0419	0.0139
Georgia	0.0153	0.0154	0.0197	0.0154
Iowa	0.0111	0.0070	0.0132	0.0070
Idaho	0.0000	0.0027	0.0029	0.0027
Illinois	0.0661	0.0749	0.0538	0.0749
Indiana	0.0494	0.0516	0.0219	0.0516
Kansas	0.0084	0.0083	0.0121	0.0083
Kentucky	0.0069	0.0130	0.0110	0.0130
Louisiana	0.0202	0.0204	0.0129	0.0204
Massachusetts	0.0236	0.0223	0.0367	0.0223
Maryland	0.0160	0.0163	0.0142	0.0163
Maine	0.0007	0.0009	0.0053	0.0009
Michigan	0.0439	0.0525	0.0377	0.0525
Minnesota	0.0042	0.0065	0.0205	0.0065
Missouri	0.0174	0.0158	0.0216	0.0158
Mississippi	0.0011	0.0093	0.0074	0.0093
Montana	0.0014	0.0014	0.0026	0.0014
North Carolina	0.0091	0.0098	0.0219	0.0098
North Dakota	0.0000	0.0014	0.0031	0.0014
Nebraska	0.0007	0.0027	0.0075	0.0027
New Hampshire	0.0014	0.0023	0.0055	0.0023
New Jersey	0.0759	0.0711	0.0516	0.0711
New Mexico	0.0028	0.0023	0.0035	0.0023
Nevada	0.0000	0.0005	0.0026	0.0005
New York	0.0717	0.0581	0.0915	0.0581
Ohio	0.0703	0.0702	0.0485	0.0702

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a/ Source: Part A Permit Application Data (1979-1980).

b/ Source: ICF Incorporated, et al., Economic Analysis of Resource Conservation and Recovery Act Regulations for Small Quantity Generators, prepared for EPA, OSW, June 1985, pp. C-1 to C-16.

c/ We assumed that the distribution for accumulation tanks is equal to the distribution for storage tanks.

EXHIBIT 4-23
(Continued)

DISTRIBUTION OF TANK CATEGORIES WITHIN EACH STATE

State	Treatment [a] Tanks	Storage [a] Tanks	SQG [b] Tanks	Accumulation [c] Tanks
Oklahoma	0.0105	0.0158	0.0121	0.0158
Oregon	0.0035	0.0060	0.0094	0.0060
Pennsylvania	0.0508	0.0423	0.0618	0.0423
Rhode Island	0.0028	0.0033	0.0085	0.0033
South Carolina	0.0125	0.0107	0.0100	0.0106
South Dakota	0.0	0.0	0.0029	0.0
Tennessee	0.0056	0.0079	0.0160	0.0079
Texas	0.1149	0.1339	0.0615	0.1339
Utah	0.0049	0.0051	0.0046	0.0051
Virginia	0.0118	0.0174	0.0162	0.0174
Vermont	0.0021	0.0019	0.0026	0.0019
Washington	0.0105	0.0058	0.0139	0.0058
Wisconsin	0.0195	0.0233	0.0253	0.0233
West Virginia	0.0140	0.0135	0.0045	0.0135
Wyoming	0.0014	0.0019	0.0015	0.0019

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[a] Source: Part A Permit Application Data (1979-1980).

[b] Source: ICF Incorporated, et al., Economic Analysis of Resource Conservation and Recovery Act Regulations for Small Quantity Generators, prepared for the Office of Solid Waste, EPA, June, 1985, pp. C-1 to C-16.

[c] We assumed that the distribution for accumulation tanks is equal to the distribution for storage tanks.

EXHIBIT 4-24

HYDROGEOLOGIC SETTING WEIGHTS

Tank Category	Ground-water Scenario a/								
	A	B	C	D	E	F	G	H	I
Treatment	0.1068	0.1454	0.1555	0.0724	0.0390	0.1444	0.1452	0.0346	0.1564
Storage	0.1103	0.1440	0.1515	0.0720	0.0420	0.1430	0.1427	0.0358	0.1590
Small Quantity Generators	0.1018	0.1500	0.1583	0.0767	0.0359	0.1482	0.1412	0.0391	0.1484
Accumulation	0.1103	0.1440	0.1515	0.0720	0.0420	0.1430	0.1427	0.0358	0.1590

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a/ See Chapter 3 for a description of these ground-water scenarios.

4.4.4 Assumptions and Limitations

The approach for determining the percentage of a tank category located within each ground-water scenario is based on the assumption that the tank population is distributed across the whole state. For example, suppose four ground-water scenarios are located within a state. We have assumed that the tank population within the state is distributed evenly among the settings. In actuality, although four scenarios exist in the state, all the tanks may be located in only two of the settings. Because we do not have information on the ground-water settings underlying the existing tank population, we do not know what type of effect this assumption will have on the national risk estimate (i.e., underestimate or overestimate the risk). Of note is that the modeling framework that we have developed is flexible such that we can use better information if it becomes available. We need only to modify the percentages in Exhibits 4-20 through 4-23.

4.5 SELECTING REPRESENTATIVE RELEASE PROFILES

As noted in Section 4.1, the Hazardous Waste Tank Failure model generates up to 250 release profiles for each of the 22 tank technologies under each regulatory scenario.[22] We initially considered running each of these 250 profiles through the Tank Risk Analysis Model (TRAM), however, this would be computationally intensive. We subsequently decided to use a weighted representative sample of the 250 profiles generated by the HWTF model in the risk analysis.

Several alternative techniques for choosing representative release profiles were considered. These included simply characterizing each profile by its total release volume, then dividing the profiles into groups with similar total releases, and, finally, picking the profile with the median total release for each group. Other more involved techniques that were also based on first computing summary measures for each profile, such as the standard deviation and number of zero releases, and then grouping profiles on the basis of these summary measures were examined and subsequently discarded in favor of the technique used, namely, cluster analysis. The latter technique, which is described below, was considered superior because it takes into account all the characteristics of a profile and not just a handful, such as the total release or the number of zero releases. In particular, it takes into account the timing of releases, which is an important component (i.e., purpose) of the HWTF model.

The cluster analysis procedure we used to select representative release profiles consisted of the following three steps:

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[22] For tanks whose age was less than the median tank age, fewer than 250 profiles were generated. However, for ease of exposition, the above discussion assumes 250 profiles were generated in all cases.

1. Determine the appropriate number of profile groups.

2. Divide each set of 250 profiles into groups of similar profiles, where the number of groups is that determined in step 1.

3. Select a representative profile from each group.

Thus, we divided each set of 250 profiles into five or six clusters (i.e., groups) of similar profiles, and chose a single representative profile from each cluster. The three basic steps are discussed in turn below.

4.5.1 Determining the Number of Profile Groups

The number of profile groups was determined by the presence or absence of profiles with zero release volumes for the entire 20-year time horizon. If such "zero profiles" were absent in a set of 250 profiles, we divided the profiles into five groups. On the other hand, if zero profiles were present, we divided the 250 profiles into six groups, with the sixth group consisting entirely of zero profiles.

Test runs indicated that, in general, little was gained in terms of better grouping of profiles by increasing the number of profile groups to seven or more. However, if fewer than five groups were used, dissimilar profiles would frequently be placed in the same group.

4.5.2 Grouping Similar Profiles

Profiles were divided into groups (or "clusters") using a standard statistical technique known as cluster analysis. Specifically, the SAS (Statistical Analysis System) statistical package program FASTCLUS was used. Before inputting the profiles to FASTCLUS, all zero profiles (if any) were removed and placed in a separate group. The remaining profiles were then divided into five groups of similar profiles using the FASTCLUS procedure.

FASTCLUS performs a variant of the k-means method for non-hierarchical cluster analysis.[23] In this particular application, FASTCLUS performed the following four steps:

1. To initiate the clustering process, FASTCLUS selects five profiles to be used as "cluster seeds." These profiles are chosen so that they reflect the variation in the total set of 250 profiles.

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[23] A detailed description of the FASTCLUS procedure is presented in Chapter 18 of the SAS User's Guide: Statistics, Version 5 Edition (Cary, North Carolina: SAS Institute, 1985). The description presented here is adapted from Romesburg, C.H., Cluster Analysis for Researchers, Belmont, California: Lifetime Learning Publications, 1984, pp. 295-296.

2. FASTCLUS then forms temporary clusters (i.e., groups of profiles) by sequentially assigning each of the remaining profiles to the cluster seed closest to it.[24] As profiles are assigned to clusters, the cluster seed is recomputed and set equal to the mean of the profiles assigned to the cluster. Consequently, the cluster seeds generally change as profiles are assigned to clusters.

3. After all the profiles have been assigned to clusters, the first iteration is complete. The final cluster seeds from the first iteration are then taken as the initial seeds for the second iteration. The process described in steps 1 and 2 is repeated: profiles are sequentially assigned to the nearest cluster seed, and the seeds are updated as the process continues. This interative procedure ensures that the final clusters obtained are the best possible ones.

4. A maximum of 10 iterations are carried out. If the change in cluster seeds from one iteration to the next satisfies the standard (default) convergence criterion in FASTCLUS, the program terminates. More specifically, iterations terminate when the maximum distance by which any seed has changed is less than or equal to the minimum distance between initial seeds times 0.02. In virtually all cases, the program terminated before reaching the tenth iteration.

4.5.3 Selecting Representative Profiles from Clusters

The output of the FASTCLUS procedure is a set of five clusters of similar (non-zero) release profiles. The final step of the selection procedure is to pick a representative profile from each cluster. The profile closest to the

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[24] The criterion used to determine whether or not profiles were similar (i.e., close) was the "distance" between profiles. The distance between two profiles is calculated by first subtracting one profile from the other profile, then squaring each of the differences, adding up the squared differences, and finally taking the square root of the resulting sum. More precisely, the Euclidean distance measure, (i.e., the distance between two profiles) is given by the square root of the sum of squared deviations:

$$\left[\sum_{t=1}^{20} (v_t^i - v_t^j)^2\right]^{\frac{1}{2}}$$

where v_t^i is the release volume in year t for profile i, and v_t^j is similarly interpreted.

cluster seed, which by construction is the mean of all the profiles in the cluster, was picked as the representative profile. In cases where zero profiles were present, a zero profile was selected as the sixth representative profile.

In some cases, the presence of outlier profiles, that is, profiles with very high releases relative to the majority of the profiles in the set, would force the clustering program to place dissimilar profiles into a single cluster so that the outlier profiles could be placed in separate clusters. We found in these cases that the profile closest to the cluster mean was sometimes not representative of the profiles in the cluster. Consequently, in these cases, we chose the profile that was at the median distance from the cluster mean. We found this profile was consistently representative of the profiles in a cluster.

4.5.4 Assumptions and Limitations

In general, the profiles chosen by the technique described above were very representative of the larger set of profiles from which they were drawn. Moreover, the technique ensured a systematic and consistent approach to selecting representative profiles. The primary limitation of the technique is the reliance on a fixed number of non-zero representative release profiles (five). As noted earlier, in the majority of cases, five clusters were found to be sufficient in that similar profiles were placed in the same cluster and dissimilar profiles were placed in different clusters. However, in some cases, the presence of outlier profiles induced dissimilar profiles to be placed in the same group. As described above, this problem was at least partly remedied by altering the criterion used to choose representative release profiles in these cases.

In the situation just described, five non-zero profile clusters proved to be too few. In other cases encountered, less than five clusters were needed. This was especially true for some of the sets of release profiles developed for the secondary containment regulatory scenario. For these sets, a very large proportion of the release profiles generated were zero profiles. When dividing the small number of non-zero profiles for these cases into clusters, it was therefore common for outlier profiles to be placed in separate clusters, rather then being placed together in a single cluster. This implied that more than one of the representative profiles chosen was an outlier profile. However, this does not constitute a significant problem as long as the representative profiles are considered along with their weights, i.e., the proportion of the total number of profiles that they represent (see Section 4.1.4 for a detailed description of these weights).

CHAPTER 5

RESULTS AND CONCLUSIONS

5.1 INTRODUCTION

In this chapter, we present the results of our risk analysis for hazardous waste tanks under the five regulatory scenarios outlined in Chapter 1. As discussed in Chapter 1, our analysis consisted of two major components:

- An analysis of some of the more common failure events associated with hazardous waste tanks, and an estimation of the volumes of liquid released due to these events over a 20-year time horizon; and
- A quantitative assessment of the relative risks over a 400-year period to individuals living in close proximity to hazardous waste tanks, via the exposure pathway of contaminated ground-water, resulting from the release of hazardous waste from these tanks.

In this chapter, we present results for the HWTF model analysis and the risk analysis separately, so that some insight may be gained into both the failure events and release volumes, and the risks associated with the population of model tank technologies under the different regulatory scenarios.

This chapter is divided into three sections after this Introduction section. HWTF model results are presented in Section 5.2, and results of the risk analysis are presented in Section 5.3. Finally, Section 5.4 presents a brief discussion of the effects of hydrogeologic settings and waste stream characteristics on the risks associated with hazardous waste tanks. Before presenting these results, however, it is important to note that the results presented in this chapter are preliminary, and thus may be subject to significant revisions following further review and additional modeling work (e.g., inclusion of an algorithm to account for the development of cracks over time in concrete tanks and an algorithm to model vadose monitoring for appropriate volatile constituents).

TRAM, and particularly the HWTF component model, is a large and relatively complex model that relies on major assumptions resulting from the lack of data in some cases, and it is clear that certain model results are driven by these assumptions (e.g., assumptions on leak detection through casual inventory control). Some of the results seem anomalous and we are reviewing the assumptions on which these results are based to determine if revised assumptions should be made. However, we believe our review of the results of this very complex model can be greatly aided by comments we expect to receive on these preliminary results.

The five regulatory scenarios considered in our analysis and presented in detail in Chapter 1 are as follows:

- **Baseline**. Under this scenario, all 22 model tank technologies are included, and are considered to be operated according to good management practices under current regulations.
- **Secondary Containment**. In this scenario, all 22 model tank technologies are included; all tanks are considered to be new, and are equipped with full secondary containment systems and interstitial monitoring (leak detection) devices.
- **Partial Secondary Containment with Ground-Water Monitoring**. This scenario applies to above-ground, ongrade tanks and in-ground tanks, and includes 10 of the 22 model tank technologies included in the analysis. These tanks are retrofitted with concrete pads, trenches, and diking that contain all above-ground portions of the tank, and are equipped with saturated zone monitoring wells located 10 meter downgradient from the tank. Of note is that in-ground and ongrade portions are not contained within the containment system.
- **Corrosion Protection**. This scenario includes 12 steel tank systems that have some portion of their systems in contact with soil (12 of 22 model tanks). These tanks are assumed to be equipped with cathodic protection (i.e., impressed current) that significantly reduces external corrosion of the tank and ancillary equipment.
- **Leak-Testing with Ground-Water Monitoring**. This scenario includes all underground tanks (7 of the 22 model tanks), and assumes that all tanks are leak tested semi-annually. In addition, all tanks are equipped with saturated zone monitoring wells located 10 meters downgradient from the tank.

Exhibit 5-1 presents the model tank technologies included in each of the five regulatory scenarios.

In the next section, we present HWTF results for these five regulatory scenarios. Risk results for the scenarios are compared in Section 5.3. Once again, however, we caution that these results are preliminary, and are considered useful only for comparing differences in release and risk estimates for the different scenarios described above. Differences in waste streams, tank sizes and tank ages currently preclude the use of these results for rigorous tank-to-tank comparisons within a scenario. However, the models used in the analysis are flexible enough to be used for tank-to-tank comparisons if slight adjustments to the model tank data bases are made. Thus, we have the capability to perform other comparisons using our analytical approach.

EXHIBIT 5-1

APPLICABLE TANK TECHNOLOGIES FOR EACH REGULATORY SCENARIO

Tank Technology	Baseline	Secondary Containment	Partial Containment with Ground-water monitoring	Corrosion Protection	Leak Testing with Ground-water Monitoring
Treatment:					
On cradles, closed top, carbon steel	X	X			
On cradles, open top, carbon steel	X	X			
Above-ground, ongrade, carbon steel	X	X	X	X	
In-ground, concrete	X	X	X		
In-ground, carbon steel	X	X	X	X	
In-ground, stainless steel	X	X	X	X	
Storage:					
On cradle, carbon steel	X	X			
Ongrade, carbon steel	X	X	X	X	
Underground, carbon steel	X	X		X	X
Underground, FRP	X	X			X
Underground, stainless steel	X	X		X	X
In-ground, concrete	X	X	X		
In-ground, carbon steel	X	X	X	X	
Small Quantity Generator:					
Above-ground, carbon steel	X	X			
Under-ground, carbon steel	X	X		X	X
Accumulation:					
On cradles, carbon steel	X	X			
Ongrade, carbon steel	X	X	X	X	
Underground, carbon steel	X	X		X	X
Underground, FRP	X	X			X
Underground, stainless steel	X	X		X	X
In-ground, concrete	X	X	X		
In-ground, carbon steel	X	X	X	X	

5.2 HAZARDOUS WASTE TANK FAILURE MODEL RESULTS

In this section we discuss the Hazardous Waste Tank Failure (HWTF) model results for the five proposed regulatory scenarios. The primary purpose of this discussion is to provide an overview of the types of results generated by the HWTF model. Consequently, we do not discuss the results for all five proposed regulatory scenarios in detail. Instead, we focus on the results for the baseline and secondary containment scenarios. A detailed discussion and comparison of the HWTF model results for all five scenarios would, in large part, be redundant since those results are mirrored in the risk estimate results presented and discussed in Section 5.3 for all five scenarios. Differences in risk estimates across the five scenarios primarily reflect differences in the HWTF model results.

We summarize the HWTF model results using two basic types of summary statistics: aggregate failure frequency data and representative release profiles (RRPs). The frequency data provide an indication of the percentage of model tanks for which a specific failure event is likely to occur. The representative release profiles for the tank technologies indicate the releases likely to result from the various failure events. These are the release profiles that we used to generate the risk estimates.[1] Below we first describe how we summarized the HWTF model results and then discuss the baseline and secondary containment results. (Summaries of the HWTF model results for all five regulatory scenarios are presented in the Appendix to this report.)

5.2.1 Types of Summary Statistics

Aggregate failure frequency data. Selected failure frequency data for a hypothetical tank technology are presented in Exhibit 5-2.[2] A brief description of each of the failure events is provided below.

- Hose ruptures. The pump-out hose may rupture when the tank contents are periodically removed. Hose ruptures are modeled only for storage/accumulation and SQG tanks.

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[1] See Section 4.5 for a detailed description of the methodology we used to select the RRPs.

[2] It should be emphasized that the list of failure events in Exhibit 5-2 is not exhaustive: several events included in the HWTF model that were considered to be of lesser importance are not presented in the table. The omitted events are first, second, and third pipe and tank replacements; and overflows, pipe/tank ruptures, pipe/tank corrosion, and weld/gasket failures beyond the first occurrence (e.g., second and third overflows).

EXHIBIT 5-2

SAMPLE FAILURE FREQUENCY DATA a/

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.9	0.0	0.4	0.4	0.0	15.2	4.5	0.9	4.9	5.8	0.0
2- 5	0.4	8.0	1.3	0.0	0.0	0.4	13.4	1.7	2.6	1.6	21.5	0.4
6-10	0.4	7.5	0.9	0.0	0.0	0.0	13.8	1.2	2.1	1.7	23.3	1.3
11-15	1.2	4.8	2.7	0.0	0.0	0.0	8.0	3.0	3.5	3.1	18.3	0.4
16-20	0.4	8.5	0.4	0.4	0.0	0.4	9.3	2.5	3.0	3.1	10.1	0.0
TOTAL	2.4	29.7	5.3	0.8	0.4	0.8	59.7	12.9	12.1	14.4	79.0	2.1

a/ Frequencies are expressed as percent of iterations in which specified failure event occurred.

- Loose hose connection. The flexible hose connection may become loose during pump-out. As for hose ruptures, this failure event is modeled only for storage/accumulation tanks and SQG tanks. (We do not model the transport of contaminants to and from treatment tanks, consequently hose ruptures and loose hose connections are not modeled for treatment tanks.)

- Overflow. This event corresponds to the overflow of waste from the tank. It can result from a level indicator or level controller failure, an operator error, or a mechanical failure of the inlet valve. However, an overflow can occur only if the tank is also nearly full, the shut-down system fails, and there is an escape route for the waste (e.g., an open top or vent).

- Improper weld or gasket installation. An improper weld installation might be caused by use of an insufficient weld thickness, while an improper gasket installation may be due to use of a defective gasket or damage to the gasket during installation.

- Pipe installation deficiency. A pipe installation deficiency may result from the use of pipe that was damaged prior to installation or by damage to the pipe during installation.

- Tank installation deficiency. A tank installation deficiency may occur due to the same reasons cited for the pipe installation deficiency.

- Weld or gasket failure. This event may be caused by the rupture of the weld, or erosion or corrosion of the gasket.

- Pipe rupture. A pipe may rupture due to poor material selection, inadequate structural support, settling action after installation, freeze/thaw cycles, or vehicle collisions.

- Tank rupture. A tank rupture may be caused by inadequate structural support, insufficient material strength, or vehicle collisions.

- Pipe corrosion. Pipe corrosion leaks may occur due to localized exterior corrosion, localized interior corrosion, or generalized corrosion.

- Tank corrosion. As for piping, tank corrosion leaks may be caused by localized exterior corrosion, localized interior corrosion, or generalized corrosion.

- Catastrophic events. Several events may cause a catastrophic failure of a tank system. These include acts of vandalism, high winds, earthquake, floods, or an explosion.

The entries in Exhibit 5-2 represent the percentage of the approximately 250 profiles generated by the HWTF model in which specific failure events occurred during a given interval of time. For example, the second entry in the second column of the table indicates that in 0.4 percent of the iterations a hose rupture occurred during years two to five of the model period. Proceeding down the second column of the table, it can be seen that hose ruptures were just as frequent during years six to ten and years sixteen to twenty, but were three times as frequent during years eleven to fifteen (1.2 percent of all profiles). In total, hose ruptures occurred in 2.4 percent of the profiles at some time during the modeled 20-year time horizon. Exhibit 5-2 also reveals that the most frequent failure event is tank corrosion (79 percent of all profiles), followed by weld/gasket failures (59.7 percent) and loose hose connections (29.7 percent).

It should be noted that in order to model the existing population of tanks, the HWTF simulates the occurrence of failure events (e.g., corrosion) prior to the first year of the model period. In Exhibit 5-2, events occuring prior to the first year of the model period are included with those occuring in the first year itself. Thus, the first row of data in the exhibit represents failures occurring before and during year one of the model period.

For some events, the data in the first row only represent failures occuring in the first year. These events include hose ruptures, loose hose connections, overflows and catastrophic events. These types of events either do not result in releases for a long period of time (i.e., a year) or result in replacement of the tank. Consequently, these events are not representative of the physical state of the existing tank population and their frequency of occurrence in the past is not reported.

Representative Release Profiles (RRPs). Representative release profiles for a hypothetical tank technology are presented in Exhibit 5-3. For purposes of exposition, release volumes are not presented for each year; instead they are summed over 5-year intervals. For instance, for the first representative release profile (RRP) listed in Exhibit 5-3, releases to the environment occurred only during the first ten and last five years of the model period. Over this period, a total of 5.666 m^3 of contaminants were released. In contrast, for the second RRP, releases occurred during each of the four time intervals, and the total release over the model period is 10.608 m^3.

It should be emphasized that even if the entries for two different RRPs are identical for a given time interval, this does not imply that the time pattern of releases is the same for the two RRPs over that time interval. For example, suppose the release volumes for the first RRP during years one to five are (5, 5, 5, 5, 5 m^3), while those for the second RRP are (0, 0, 0, 0,

EXHIBIT 5-3

SAMPLE REPRESENTATIVE RELEASE PROFILES

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.759	1.730	1.316	0.000	2.620	5.666
2	.127	0.926	1.378	2.554	5.750	10.608
3	.051	3.620	8.677	3.500	2.499	18.296
4	.042	0.658	1.080	0.000	6.923	8.661
5	.017	0.000	0.000	0.000	0.000	0.000
6	.004	13.431	25.400	6.214	0.544	45.589
WEIGHTED AVERAGE	1.000	1.697	1.763	0.528	3.139	7.127

25 m^3). For both profiles, the total volume released over the 5-year interval is 25 m^3, however the time pattern of releases is very different for the two profiles. This difference in the time pattern can influence the risks associated with the releases.

In addition to the RRPs, Exhibit 5-3 presents the weights associated with each RRP. As discussed in Section 4.1.4, these weights reflect the proportion of the approximately 250 profiles that each RRP represents. Thus, the first RRP in Exhibit 5-3 represents 75.9 percent of the roughly 250 profiles; or, stated somewhat differently, 75.9 percent of the 250 profiles generated are similar to the first RRP. The weights of the other RRPs can be interpreted in the same way. Note that the RRPs in Exhibit 5-3 are listed in order of decreasing weight. This convention is adopted in all the RRP exhibits contained in this report. The first RRP listed in each of these exhibits is therefore the RRP with the largest weight and will be referred to as the most representative release profile (MRRP). The MRRP is not necessarily the representative release profile with the largest release volume or the profile that results in the highest risk.

By multiplying each RRP by its weight, and summing over all RRPs, a weighted-average representative release profile can be derived. This provides a convenient summary of all 250 release profiles. The weighted-average release profile for the RRPs in Exhibit 5-3 is presented at the bottom of the table. Although the weighted-average profile is a convenient summary measure, it should be interpreted with caution since it is not an actual, simulated release profile. As such, it may not reflect a plausible combination of failure events. We do not use the weighted-average release profile at any point in our analysis, and it is presented in the exhibits only to facilitate comparison of the RRPs.

In the next section, we discuss the failure frequency data and RRPs for each of the 22 technologies modeled under the baseline regulatory scenario. Since accumulation tanks and storage tanks have the same release profiles and failure rates, only 15 sets of RRPs and failure rate data are discussed. In the final section, we summarize the results for the secondary containment regulatory scenario. Throughout our discussion we present summary data and general trends in the results. In order to reduce the length of this chapter, we present the detailed failure frequency data and actual representative release profiles for each regulatory scenario in the Appendix.

5.2.2 Results for the Baseline Regulatory Scenario

In this section, we summarize the baseline results for each tank category modeled (i.e., treatment, accumulation/storage, and small quantity generators). For each tank technology, we discuss the failure frequency data and representative release profiles.

Treatment Tanks

The design specifications for each of the six model treatment tanks are summarized in the following table. Except for the distillation tank, the aqueous generic waste stream was used when modeling all treatment tanks.

Location	Process	Material	Size (gallons)	Size (m^3)
on cradles	distillation	carbon steel	2,300	8.7
on cradles	oxidation/reduction/precipitation	carbon steel	2,300	8.7
ongrade	oxidation/reduction/precipitation	carbon steel	60,000	227.1
in-ground	oxidation/reduction/precipitation	concrete	3,700	14.0
in-ground	oxidation/reduction/precipitation	carbon steel	3,700	14.0
in-ground	oxidation/reduction/precipitation	stainless steel	3,700	14.0

Exhibits A-1 (pp. A-2 to A-8) and A-4 (pp. A-28 to A-34) of the Appendix present the failure frequencies and RRPs, respectively, for each of the above treatment technologies. We briefly discuss the results for each technology below.

On cradles, carbon steel, 2,300 gal., distillation tank. The most common failure events for this technology are overflows, pipe corrosion, and weld/gasket failures. Except for overflows and weld/gasket failures, failures tend to occur more frequently after the first five years of the 20-year time horizon modeled. This increase in the occurrence of events is due to the aging of the tank's components. Overflows are simulated to occur frequently for distillation tanks because the distillation tank is modeled as a batch distillation process with no automatic shut-off system to prevent overflows. It should be noted that the frequency data for overflows corresponds to the first overflow. The frequencies of subsequent overflow events were not summarized, but they were simulated to occur throughout the modeled 20-year time horizon.

On the whole, the RRPs for this technology are quite similar, with total releases only ranging from 50 m^3 to 70 m^3. Moreover, the releases are quite uniformly distributed over the four time intervals for all five RRPs.

On cradles, carbon steel, 2,300 gal., oxidation/reduction/precipitation (ORP) tank. The frequency data for this technology are very similar to those for the distillation tank. The primary differences are the much lower occurrence of pipe corrosion (38.7 percent vs. 91.8 percent), and the more uniform occurrence of overflows in the four time intervals for the oxidation/reduction/precipitation (ORP) tank. We cannot explain this difference in the frequency of pipe corrosion at present, and we are in the process of investigating it. The difference in the occurrence of overflows is due to the differences in the process control systems that we modeled for each tank. The ORP tank is modeled as a continuous process with an automatic shut-off system to prevent overflows.

Although the failure data for the distillation and ORP tanks are similar, the RRPs for these technologies differ markedly. The first RRP for the ORP tank (see Exhibit A-4, p. A-28), which represents nearly 84 percent of all generated profiles, has a total release of only 5.67 m^3. The smaller releases for the ORP tank, relative to the distillation tank, are due primarily to the more frequent occurrence of overflows for the distillation tank.

Ongrade, carbon steel, 60,000 gal., ORP tank. The frequency data for this tank technology are very similar to those for the 2,300 gallon, ORP tank. The only notable difference is the lower occurrence of tank corrosion for the 60,000 gallon, ongrade tank (48.5 percent vs. 67.4 percent). This difference is due to the fact that the ongrade tank has a thicker wall than the on cradles tank (one-half inch vs. one-quarter inch). However, examining the relevant RRPs in Exhibit A-4 (p. A-29), it can be seen that the releases for the 60,000 gallon, ongrade tank are far larger than those for the 2,300 gallon tank on cradles. For instance, the total release volume for the most representative release profile (MRRP) for the 2,300 gallon, tank on cradles is 5.67 m^3, whereas the corresponding volume for the 60,000 gallon, ongrade tank is 67.53 m^3. This difference is primarily a function of the tank sizes (2,300 gallons vs. 60,000 gallons).

In-ground, 3,700 gal., concrete, carbon steel, and stainless steel ORP tanks. These three technologies differ only in terms of the material from which the tanks are made. With a few notable exceptions, the failure data for the three technologies are very similar to each other and to the failure data for the treatment technologies discussed above.[3] The primary differences are in the occurrence of pipe and tank corrosion. The lowest occurrence of pipe corrosion is for the stainless steel tank (28.1 percent), followed by the carbon steel tank (35.7 percent), and the concrete tank (44.1 percent). The frequency of tank corrosion is lowest for the concrete tank (0 percent) since concrete tanks do not corrode. Carbon steel tanks have the least corrosion resistance and consequently experience the most tank corrosion (97.9 percent).

Exhibit A-4 (pp. A-30 to A-34) reveals that for all three technologies a single profile is representative of approximately 94 percent of all the profiles generated. The total releases for the MRRPs range from 25 m^3 for the stainless steel tank to 43 m^3 for the carbon steel tank. The larger releases from the carbon steel tank are due, largely, to the higher occurrence of tank corrosion failures for this technology. For all three technologies, there are a small proportion of profiles with release volumes that far exceed those of the MRRPs.

Comparison of treatment tank technologies. In order to highlight the similarities and differences between the treatment tank technologies, the most representative release profile (MRRP) for each technology is plotted in Exhibit 5-4. The exhibit reveals that the MRRP for the open top, on cradles,

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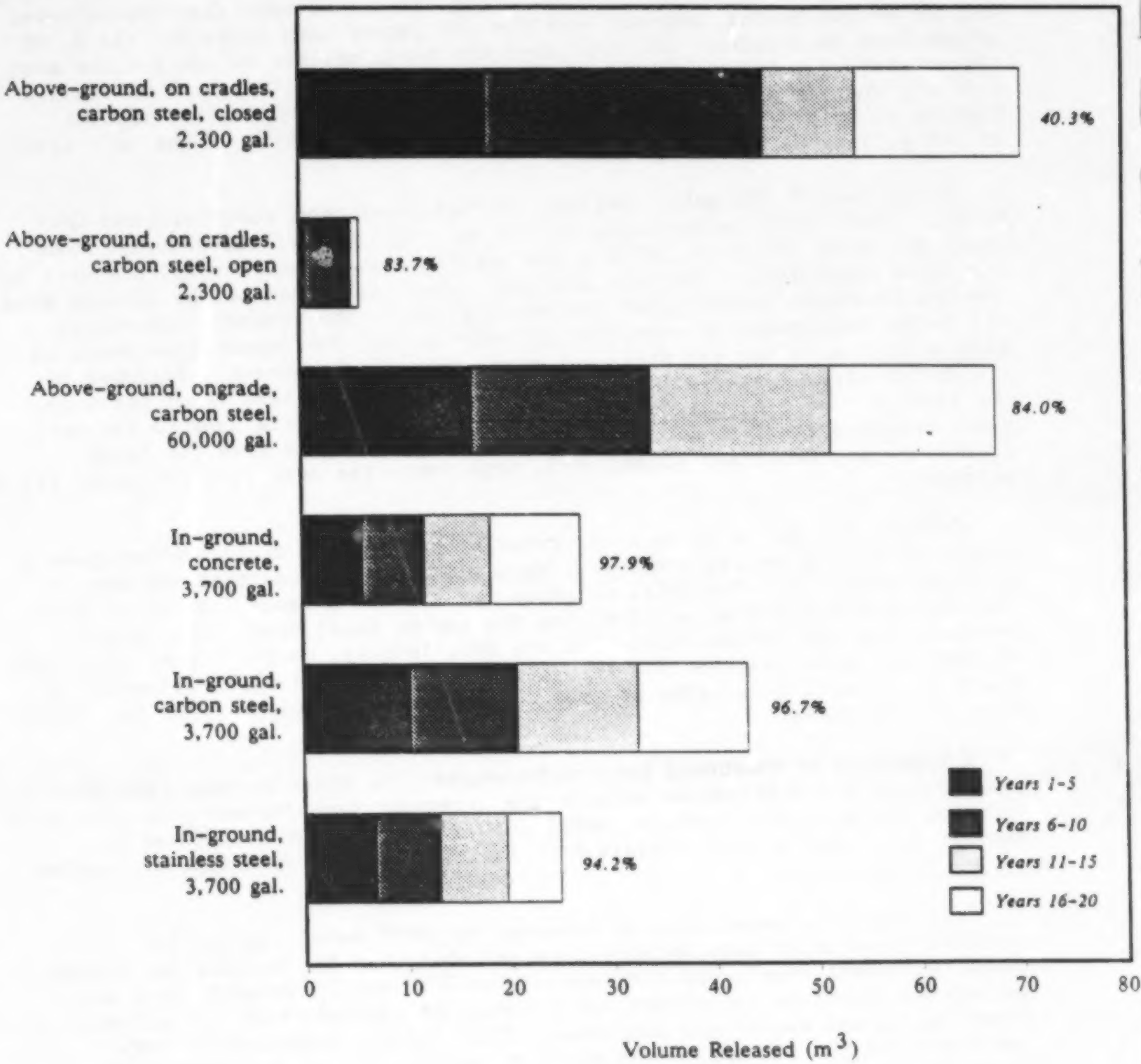
[3] It should be noted that we consider the HWTF model results for concrete tanks to be considerably less reliable than the results for carbon steel, stainless steel, and FRP tanks. The HWTF model currently does not include an algorithm to account for cracking of concrete tanks as a result of normal aging and weathering processes. This failure mechanism is very important and the failure of the model to account for it may cause concrete tanks to appear more reliable than they really are. We are currently adapting the concrete tank algorithms of the HWTF model to account for normal cracking.

EXHIBIT 5-4

MOST REPRESENTATIVE RELEASES PROFILES FOR TREATMENT TANKS

BASELINE SCENARIO



Note: Numbers next to bars indicate the percent of the 250 release profiles that the MRRP represents.

carbon steel, 2,300 gallon, ORP tank has the smallest total release volume. Along with the distillation tank, the ORP tank is the smallest treatment tank modeled. The MRRP with the largest release is that for the ongrade, 60,000 gallon, carbon steel tank.

Total failure frequency data for the treatment technologies are tabulated in Exhibit 5-5.[a] The failure data demonstrate that there is little if any variation in the frequencies of pipe ruptures across the six treatment technologies. With the exception of the distillation tank, this is also true for overflows and weld/gasket failures. The greatest absolute variation in failure frequencies is in the tank rupture, and tank/pipe corrosion categories. The frequency of catastrophic releases is roughly similar for all the technologies. Examining the data in Exhibit 5-5, it is clear that there is no technology for which failure frequencies are uniformly lowest. For example, although the distillation tank has relatively low frequencies of occurrence for a number of failure events, it has by far the highest frequency of pipe corrosion and overflows.

Storage/Accumulation Tanks

The hazardous waste tank Regulatory Impact Analysis (RIA) conducted by the Office of Solid Waste in 1984 indicated that although RCRA-permitted storage tanks and accumulation tanks have been regulated in a significantly different manner, the actual management practices for these tanks, such as storage time and annual throughput, are not significantly different. While the RIA indicated slight differences in storage time, these differences were on the order of a few days, and thus were too small to have a significant impact on HWTF model output. Therefore, the failure and release profile results for storage tanks were also assumed to hold for otherwise identical accumulation tanks. In total, seven storage/accumulation tank technologies were modeled. These are summarized below.

Location	Material	Size (gallons)	Size (m^3)
on cradles	carbon steel	5,500	20.8
ongrade	carbon steel	210,000	794.8
underground	carbon steel	4,000	15.1
underground	fiberglass reinforced plastic	4,000	15.1
underground	stainless steel	4,000	15.1
in-ground	concrete	2,100	7.9
in-ground	carbon steel	2,100	7.9

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[a] Hose ruptures and loose hose connections are not simulated to occur for treatment tanks because we do not model the transport of wastes to and from treatment tanks.

EXHIBIT 5-5

TOTAL FAILURE FREQUENCIES FOR TREATMENT TANKS [a]
BASELINE SCENARIO

Technology	Hose Rupture	Loose Hose	Overflow	Weld/Gasket Installation	Pipe Installation Defect	Tank Installation Defect	Weld/ Gasket Failure	Pipe Rupture	Tank Rupture	Pipe Corrosion	Tank Corrosion	Cata-strophic Release
On cradles, carbon steel, distillation	0.0	0.0	100.0	2.5	0.4	0.8	82.7	20.7	19.6	91.8	58.1	4.3
On cradles, carbon steel, ORP	0.0	0.0	76.6	4.3	1.0	1.5	90.5	26.6	23.8	38.7	67.4	5.3
Ongrade, carbon steel, ORP	0.0	0.0	73.2	4.0	0.8	3.3	93.9	24.2	30.9	34.5	48.5	6.4
In-ground, concrete, ORP	0.0	0.0	76.9	2.8	0.0	2.1	94.4	21.4	39.1	44.1	0.0	5.6
In-ground, carbon steel, ORP	0.0	0.0	76.7	4.4	0.0	0.8	93.2	21.4	36.2	35.7	97.9	5.6
In-ground, stainless steel, ORP	0.0	0.0	76.9	2.0	0.0	0.8	94.6	21.4	33.3	28.1	38.0	5.6

[a] Frequencies are expressed as percent of 250 iterations in which the failure event specified occurred.

For all storage/accumulation tanks, except the tank on cradles, separate release profiles were generated for the generic aqueous and toluene waste streams.[5] (The generic aqueous waste stream was used in modeling releases from the tank on cradles.) Thus, a total of 13 sets of failure data and representative release profiles (RRPs) were generated for storage/accumulation tanks. For all six of the technologies for which separate results were generated for aqueous and toluene wastes, failure frequencies were essentially independent of waste type, therefore failure data for only the toluene waste stream are discussed below. On the other hand, representative release profiles did vary significantly with waste type, given the importance of waste density and viscosity in determining leak rates. As a result, RRPs for all 13 runs are discussed. Failure frequency data for the storage/accumulation tanks are presented in Exhibit A-2 of the Appendix (pp. A-9 to A-23), while the RRPs are presented in Exhibit A-5 (pp. A-35 to A-49).

On cradles, carbon steel, 5,500 gal. tank. The most common failure events for this technology are weld/gasket failures, tank corrosion, loose hose connections, and overflows. Failures appear to occur primarily during the first ten years of the model period because Exhibit A-2 only presents the first occurrence of these events, and not the second, third or fourth occurrences.

Examining the RRPs for this technology, it can be seen that the total release for the MRRP is quite small (5.67 m^3). The total releases for the other RRPs range from 0 m^3 to approximately 46 m^3.

Ongrade, carbon steel, 210,000 gal. tank. The failure frequencies for this technology differ markedly from those for the 5,500 gallon tank on cradles. For both technologies, weld/gasket failures and tank corrosion are very frequent; however, the frequency of hose ruptures and loose hose connections are zero for the ongrade tank since hoses are not used to empty the tank. On the other hand, pipe corrosion occurs much more frequently for the ongrade tank given the high throughput for this tank, which results in faster pipe erosion and corrosion. Also, the pipes for the ongrade tank are 21 years old at the beginning of the model period and age contributes to high failure rates.

The RRPs for the ongrade tank, which are displayed in Exhibit A-5 (pp. A-35, A-36), reveal that relatively large volumes of waste are released from this tank. Total releases range from 342 m^3 to 82,000 m^3 for aqueous wastes, and 977 m^3 to 104,000 m^3 for toluene wastes. This may be attributed to the large size of the tank and its high throughput. Note, however, that for both waste types, the MRRPs have the smallest releases. For nearly all the RRPs, releases increase over time. This is especially true of the MRRPs for the two waste types. This time pattern of releases is a result of undetected leaks from the bottom of the ongrade tank that increase in volume over time. The model assumes that detection does not occur until 25 percent of the monthly tank throughput leaks out over a one month period.

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[5] For these technologies, tanks are in direct contact with soil. The leak rate from a tank to soil depends on the density and viscosity of the waste it contains, hence the use of two generic waste streams. Only one waste stream was necessary to estimate leak rates from tanks not in contact with soil.

Underground, 4,000 gal., carbon steel, FRP, and stainless steel tanks. These three technologies differ only in terms of the material from which the tanks are made. The major effect of tank material appears to be on the frequency of pipe/tank ruptures and corrosion. Frequencies of pipe/tank ruptures are similar for the carbon steel tank and the stainless steel tank, but are substantially higher for the fiberglass reinforced plastic (FRP) tank. This tank experiences more pipe/tank ruptures because the material strength of FRP is not as high as that of steel. However, since FRP tanks donot corrode, the frequency of pipe/tank corrosion is zero for these tanks. The carbon steel tank has more failures due to corrosion than the stainless steel tank. This difference in the occurrence of corrosion and the relative magnitudes of the release volumes discussed below indicate that corrosion is the over-riding factor influencing the magnitude of release volumes. Other events, such as overflows and pipe ruptures, do not lead to the high releases associated with corrosion.

Comparing the profiles for the three technologies in Exhibit A-5 (pp. A-38 to A-45), it can be seen that the smallest releases are associated with the FRP tank, with the stainless steel tank a close second. The total releases for the MRRPs of these two technologies are on the order of 2 m^3. On the other hand, the total releases for the carbon steel tank MRRPs are roughly two to three times this magnitude, primarily due to the higher occurrence of corrosion.

In-ground, 2,100 gal., concrete and carbon steel tanks. These two technologies also differ only in terms of the material of which the tanks are made. As the failure data for these tanks reveal, there is a somewhat higher occurrence of both pipe and tank installation deficiencies for the carbon steel tank, and a much higher occurrence of tank corrosion (79.9 percent vs. 0 percent) since concrete does not corrode. The higher occurrence of installation deficiencies is due to more frequent replacements of the carbon steel tank.

The RRPs for these tank technologies, which are presented in Exhibit A-5 (pp. A-45 to A-49), indicate that releases are larger for the carbon steel tank. This is due primarily to the higher occurrence of corrosion for the carbon steel tank, and is also a result of the HWTF model's incomplete modeling of the dominant failure mechanisms associated with concrete tanks.[6]

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[6] See footnote three for a discussion of the deficiency of the model in this regard.

Comparison of storage/accumulation tank technologies. In order to facilitate comparison of the various storage/accumulation tank technologies, the MRRP for each technology is plotted in Exhibit 5-6. For simplicity, only the toluene waste stream MRRPs are shown since they convey virtually the same information as the aqueous waste stream MRRPs. Total failure data for the storage/accumulation technologies are presented in Exhibit 5-7. Failure data are also presented only for the toluene waste stream since failure frequencies did not vary significantly with waste type.

Exhibit 5-6 shows that the MRRP with the smallest total release is for the underground, stainless steel, 2,100 gallon tank. Note that this is the smallest storage/accumulation tank modeled. The MRRP with the largest release is for the ongrade, 210,000 gallon tank made of carbon steel, which is the largest tank modeled.

The total failure data in Exhibit 5-7 reveal that there is considerable variation in the frequency of failure events across the various storage/ accumulation technologies. The highest variation is in the pipe and tank corrosion categories and the overflow category. The lowest occurrence of corrosion is in the underground FRP and stainless steel tanks, and the in-ground concrete tank; however the in-ground concrete tank has a high frequency of overflows. As in the case of the treatment tanks, no technology has uniformly lowest failure frequencies. But, the underground FRP and stainless steel tanks have relatively low failure frequencies in nearly all the categories.

The frequency of catastrophic releases and overflows differ considerably for the various storage/accumulation tank technologies. This is due to differences in the assumed decision and operating parameters for the technologies. For the above-ground and in-ground tank technologies, waste is pumped into the tanks and has a direct overflow path through either the vent pipe or the open top. In contrast, for the underground tank technologies, waste is gravity fed and the vent pipe is normally placed above the height of the fluid in the source tank. As a result, waste cannot overflow from the top of the vent pipe. The only overflow paths are through corroded vent pipes or failed weld/gasket connections.

As for the differences in the occurrence of catastrophic releases, these are less frequent for underground tanks because they are assumed not to be subject to vandalism. Moreover, a nearby fire or explosion is assumed to be one-third as likely to damage an underground tank as it is to damage an above-ground tank.

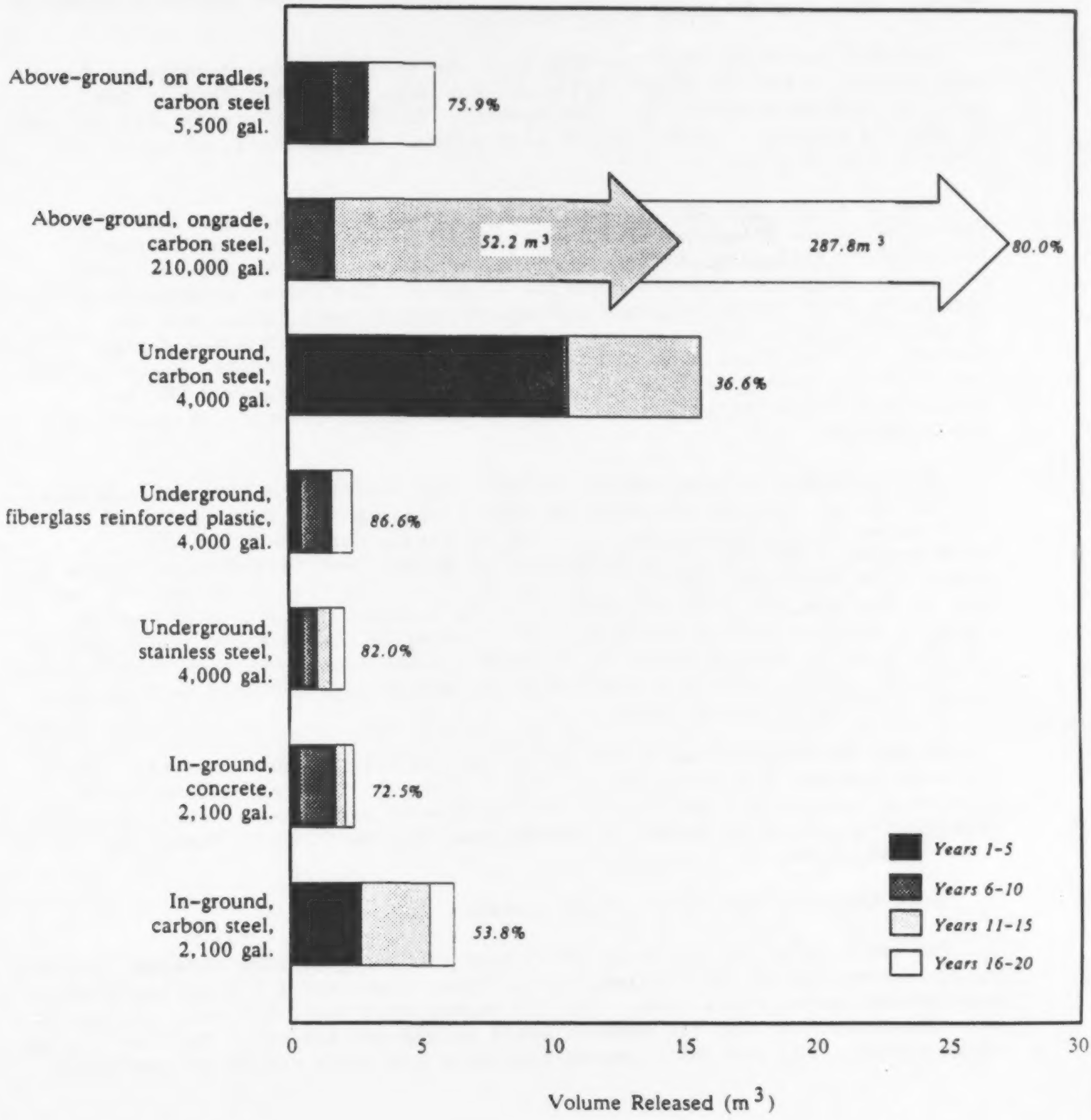
Small Quantity Generator (SQG) Tanks

Two small quantity generator (SQG) tank technologies were modeled: a 200 gallon, above-ground, on cradles, carbon steel tank, and a 200 gallon (8 m^3), underground carbon steel tank. For the underground tank, two sets of results were generated: one for the aqueous waste stream and the other for the toluene waste stream. For the above-ground tank only one waste stream is used since

EXHIBIT 5-6

MOST REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

BASELINE SCENARIO



Note: Numbers next to bars indicate the percent of the 250 release profiles that the MRRP represents.

EXHIBIT 5-7

TOTAL FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS [a]
BASELINE SCENARIO (TOLUENE)

Technology	Hose Rupture	Loose Hose	Overflow	Weld/Gasket Installation	Pipe Installation Defect	Tank Installation Defect	Weld/ Gasket Failure	Pipe Rupture	Tank Rupture	Pipe Corrosion	Tank Corrosion	Cata- strophic Release
On cradles, carbon steel	33.8	53.2	48.5	0.8	0.0	0.0	74.4	10.4	7.7	9.0	56.7	4.0
Ongrade, carbon steel	0.0	0.0	2.0	1.2	1.2	0.8	81.2	13.1	11.7	98.5	51.0	6.0
Underground, carbon steel	24.9	54.6	4.9	0.4	0.8	0.4	61.0	13.0	12.1	15.0	86.9	2.1
Underground FRP	24.5	55.6	5.6	0.4	1.3	0.0	59.1	24.3	17.3	0.0	0.0	2.1
Underground, stainless steel	25.4	52.5	5.7	0.4	0.8	0.0	59.0	13.0	12.4	4.5	12.1	2.1
In-ground, concrete	12.0	52.9	42.8	0.8	0.0	0.4	80.7	10.0	11.0	8.0	0.0	4.8
In-ground, carbon steel	12.4	49.3	41.0	1.0	0.5	2.0	78.9	10.5	9.3	12.2	79.9	5.0

[a] Frequencies are expressed as percent of 250 iterations in which the failure event specified occurred.

the tank is on cradles and not in contact with soil As a result, the leak rate from the tank does not depend on the physical properties of the waste it contains. The failure data for the SQG technologies are presented in Exhibit A-3 (pp. A-24 to A-27) of the Appendix, and the RRPs are presented in Exhibit A-6 (pp. A-50 to A-53).

Underground, 200 gal., carbon steel tank. Examining the failure data for the underground tank first, it can be seen that the failure frequencies are virtually identical for the two waste streams. The most common failure events are tank corrosion (approx. 80 percent), weld/gasket failures (approx. 60 percent), and loose hose connections (approx. 30 percent). The remaining failure events occur quite infrequently.

The RRPs for the underground tank technology suggest that smaller releases are associated with the toluene waste stream. As discussed further below, this difference may be attributed to the earlier detection of toluene releases.

Above-ground, 200 gal., carbon steel tank. The failure frequency data for the above-ground SQG tank technology indicate that weld/gasket failures, tank corrosion, and loose hose connections are also among the most common failure events for this technology. However, in contrast to the underground SQG tank, overflows occur very frequently for the above-ground tank (48 percent vs. approx. 5 percent). As discussed previously in the context of storage/accumulation tanks, above-ground tanks have direct overflow paths through either the vent pipe or open top. In contrasts, underground tanks do not tend to overflow since we assume they are gravity fed and overfilling just results in the wastes backing up in the vent pipe. Thus, the only overflow paths we model for underground tanks are through corroded vent pipes or failed weld/gasket connnections.

In addition, catastrophic releases are twice as frequent for the above-ground tank since it is assumed to be more susceptible to vandalism than an underground tank. However, tank corrosion is far less frequent for the above-ground tank (44 percent vs. 80 percent) since it is only in contact with the atmosphere and is not in contact with the corrosive environment of the soil, unlike the underground tank.

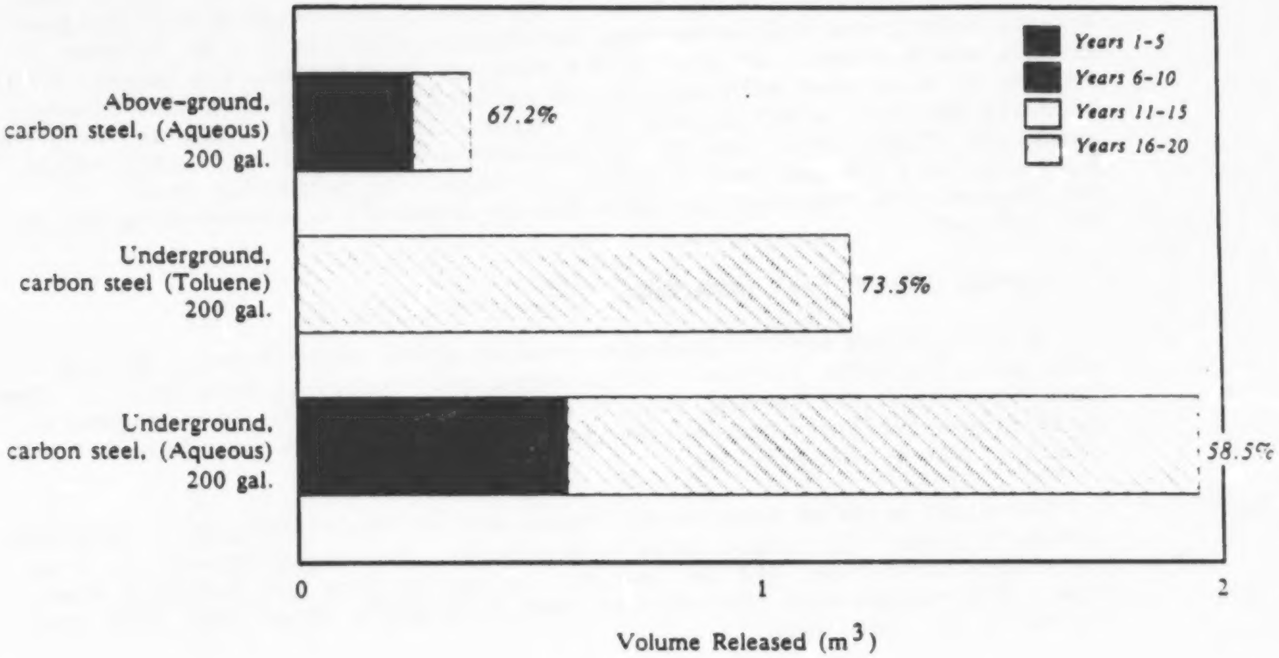
The RRPs for the above-ground SQG tank indicate that lower volumes of wastes are released relative to the underground tank.

Comparison of SQG tank technologies. A comparison of the MRRPS for the three SQG runs is presented in Exhibit 5-8. The MRRP for the above-ground SQG tank clearly has the smallest release. The MRRPs for the underground SQG tank differ somewhat in that these are positive releases during years one to five for the aqueous wastes stream but no the toluene waste stream. It should be noted, however, that the aqueous wste stream MRRP is only representative of 58.5 percent of all the release profiles. For all but one of the other RRPs for the aqeous waste stream, there are no releases during years one to five (see Exhibit A-6, p. A-51.)

EXHIBIT 5-8

MOST REPRESENTATIVE RELEASE PROFILES FOR SQG TANKS

BASELINE SCENARIO



Note: Numbers next to bars indicate the percent of the 250 release profiles that the MRRP represents.

The total failure frequencies for the SQG tank technologies are shown in Exhibit 5-9. This tabulation simply highlights the observations made above regarding the relative frequency of failure events for the two technologies.

Comparison of Tank Technologies

Exhibit 5-10 shows the total releases for the MRRPs of the fifteen tank technologies modeled. In the case of the storage/accumulation technologies and the underground SQG technology, the data plotted are for the toluene generic waste stream. As the exhibit clearly demonstrates, the largest total release is associated with the 210,000 gallon, ongrade, carbon steel storage/accumulation tank, which is also the largest tank modeled. However, with the exception of this tank, the largest releases are for treatment tanks, while SQG tanks have the smallest releases. It should be noted that these conclusions also hold with the RRPs for the aqueous waste streams, which are not plotted.

Comparison of Tank Materials

Several of the tank technologies modeled differ only in terms of tank material. The MRRPs for these technologies are plotted in Exhibit 5-11. The data plotted for the storage/accumulation tanks are for the toluene generic waste stream profiles, however the conclusions drawn below also hold for the aqueous waste stream profiles.

The first group of bars in the figure are for the 2,700 gallon, in-ground treatment tanks. For these three technologies, the largest release is from the carbon steel tank, and the smallest release is from the stainless steel tank. The release from the concrete tank is slightly larger than that from the stainless steel tank.[7]

The second group of bars in the figure are for the 4,000 gallon, underground storage/accumulation tanks. The largest release for this group is also from the carbon steel tank. The releases from the stainless steel and fiberglass reinforced plastic (FRP) tanks are similar in magnitude, however the FRP tank has a slightly larger release volume.

The final group of bars plotted in Exhibit 5-11 are for the 2,100 gallon, in-ground storage/accumulation tanks. For this group, the larger release is also from the carbon steel tank.

The above material comparisons suggest that the largest releases are consistently associated with carbon steel tanks. Conclusions regarding the material with the smallest releases are difficult to make given the combinations of tank technologies modeled and the assumptions used in the HWTF model (e.g., the cracking of concrete tanks was not incorporated in the model).

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[7] See footnote three regarding the accuracy of the HWTF model results for concrete tanks.

EXHIBIT 5-9

TOTAL FAILURE FREQUENCIES FOR SQG TANKS [a]
BASELINE SCENARIO

Technology	Hose Rupture	Loose Hose	Overflow	Weld/Gasket Installation	Pipe Installation Defect	Tank Installation Defect	Weld/ Gasket Failure	Pipe Rupture	Tank Rupture	Pipe Corrosion	Tank Corrosion	Cata-strophic Release
Above-ground	0.8	34.1	48.3	0.8	0.0	0.8	74.3	10.4	6.9	9.0	44.1	4.0
Underground (toluene)	2.4	29.7	5.3	0.8	0.4	0.8	59.7	12.9	12.1	14.4	79.0	2.1
Underground (aqueous)	2.4	29.0	5.7	0.8	0.8	1.6	60.4	13.2	11.2	14.3	80.0	2.1

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[a] Frequencies are expressed as percent of 250 iterations in which the failure event specified occurred.

EXHIBIT 5-10

MOST REPRESENTATIVE RELEASE PROFILES FOR ALL TANK TECHNOLOGIES

BASELINE SCENARIO (TOLUENE)

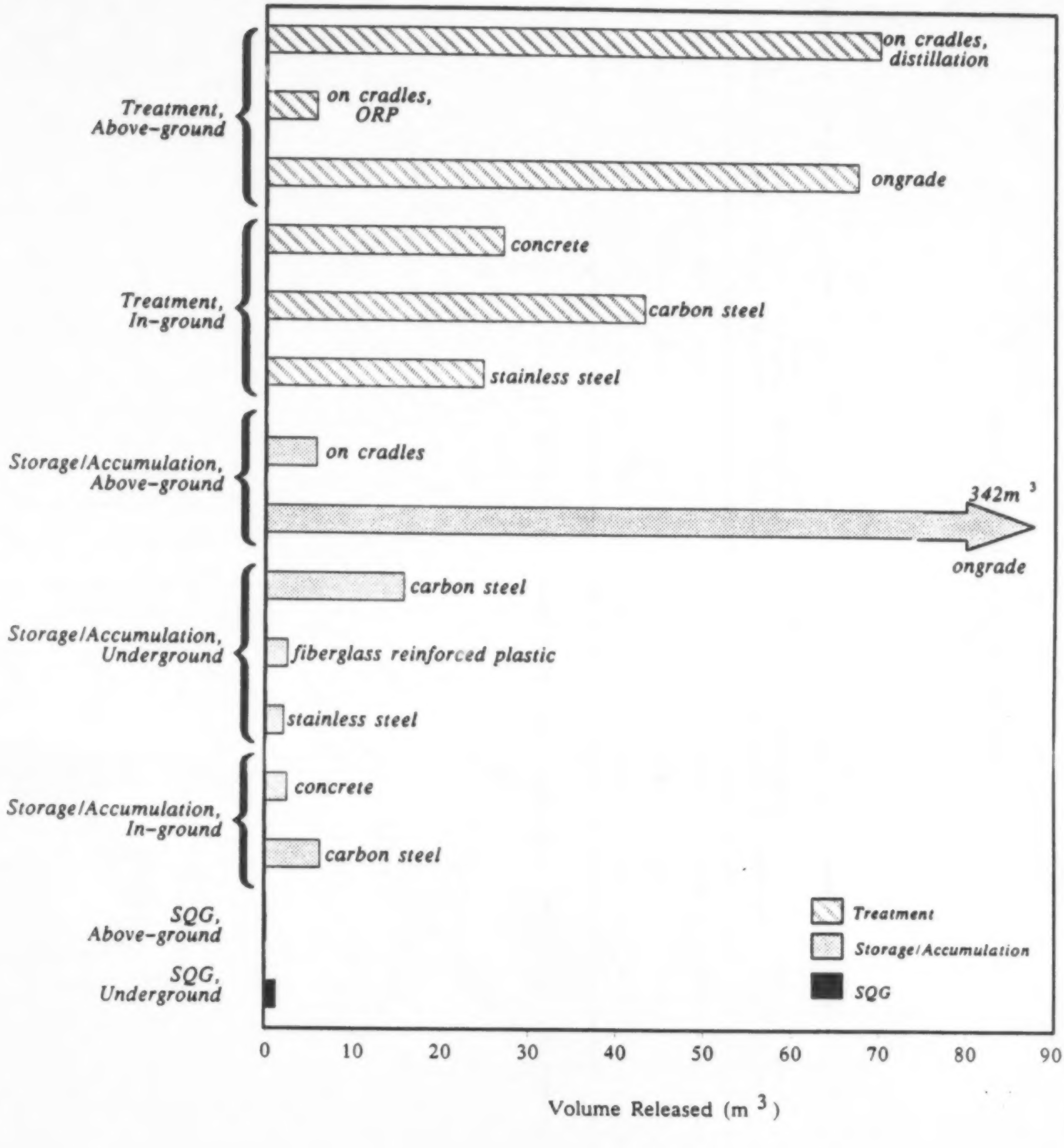
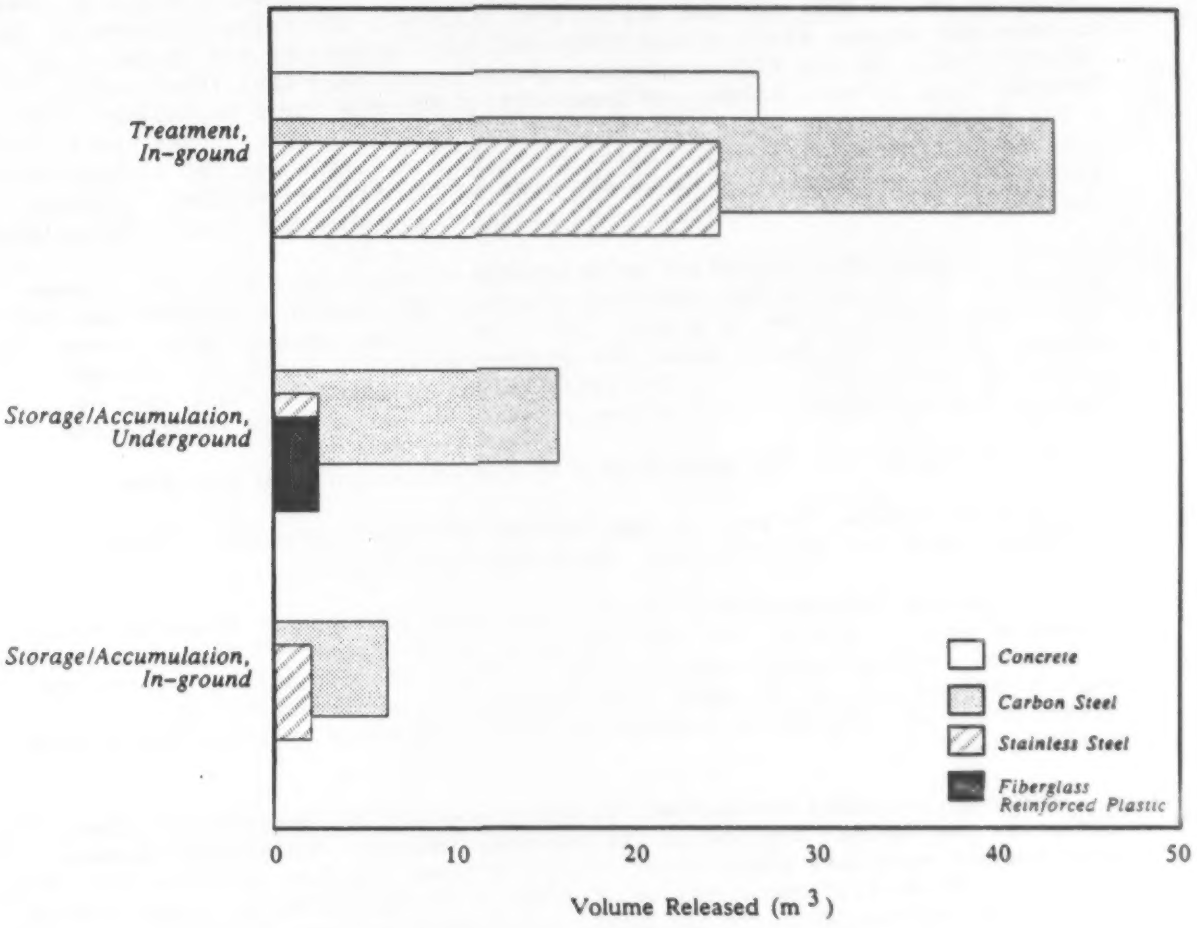


EXHIBIT 5-11

COMPARISON OF TANK MATERIALS
MOST REPRESENTATIVE RELEASE PROFILES FOR SELECTED TANKS
BASELINE SCENARIO (TOLUENE)



Comparison of Waste Types (Aqueous vs. Toluene)

As noted previously, for six of the seven storage/accumulation tank technologies and for the underground SQG tank technology, two sets of failure frequencies and release profiles were generated: one for aqueous wastes and another for toluene wastes.[a] The failure frequencies obtained for these technologies do not vary significantly with waste type, however there is some variation in the RRPs for the two sets of results. The total releases of the toluene and aqueous waste stream MRRPs for each technology are compared in Exhibit 5-12. As the figure reveals, there is no consistent relationship between total release volume and waste type. For the first technology (the 5,500 gallon, ongrade tank) and the last two (the in-ground carbon steel tank and the underground SQG tank), total releases are larger for the aqueous waste stream MRRPs, substantially so in the case of the tank on cradles. However for the remaining technologies, total releases are somewhat larger for toluene.

The absence of a consistent relationship between waste type and release volume is the result of two opposing effects. Although the release rate for the toluene waste stream is higher than that for the aqueous waste stream, an aqueous release may remain below the assumed detection limit for a longer period of time. As a result, the total volume released may be larger or smaller for the toluene waste stream relative to the aqueous waste stream.

5.2.3 Results for the Secondary Containment Regulatory Scenario

In this section, we present and discuss the representative release profiles (RRPs) for the secondary containment simulations.

The failure frequency data for the secondary containment scenario are not discussed here (although they are presented in the Appendix) since the primary purpose of secondary containment is not to alter the frequencies of failure events, but to prevent releases from reaching the environment. Our presentation is, therefore, limited to discussing the representative release profile results.

Although secondary containment is not (necessarily) designed to affect failures, the failure results in the Appendix indicate differences between baseline and secondary containment failure frequencies (see Exhibits A-1, A-2, and A-3). These difference may be attributed to the following three factors. First, the implementation of secondary containment assumes the installation of a new tank. Therefore, the frequency of tank corrosion and weld/gasket failures is lower than under the baseline scenario since corrosion is a time-dependent process and all the baseline tanks are at least five years old at the start of the model period. Second, since the secondary containment tank technologies have double walls, a single wall will not be subjected to simultaneous interior and exterior corrosion, as would be true for the

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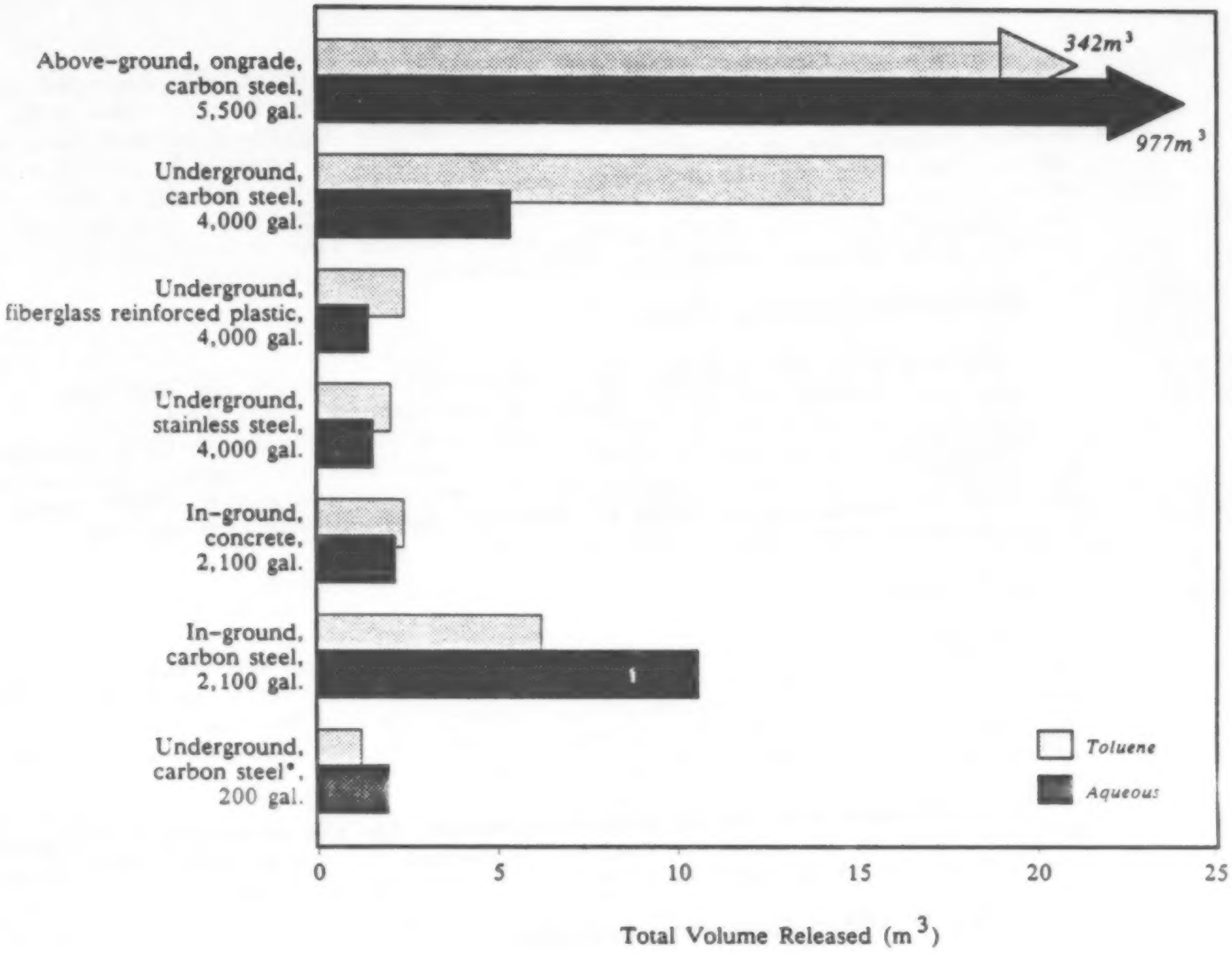
[a] Only the aqueous waste stream was used in modeling the storage/ accumulation tank on cradles since it is not in contact with soil.

EXHIBIT 5-12

COMPARISON OF WASTE TYPES MOST REPRESENTATIVE RELEASE PROFILES FOR SELECTED TANKS

BASELINE SCENARIO



* SQG tank, all others are storage/accumulation tanks

single-walled baseline tank technologies. Finally, the frequency of installation deficiencies is higher for the secondary containment scenario because new tanks are being installed.

Below we provide a general discussion of the representative release profiles for the secondary containment scenario.

Treatment Tanks

The RRPs for treatment tanks with secondary containment are presented in Exhibit A-4 of the Appendix (pp. A-28 to A-24). A comparison of these RRPs with those for the baseline treatment tanks reveals a pronounced reduction in release volumes due to secondary containment. This is especially true for the MRRPs. The MRRPs for all secondary containment treatment tanks have zero total releases, whereas the baseline MRRPs have total releases ranging from approximately 6 m^3 (the 2,300 gallon, open top, ORP tank on cradles) to 70 m^3 (the 2,300 gallon, closed top, distillation tank on cradles).

Storage/Accumulation Tanks

Exhibit A-5 of the Appendix (pp. A-35 to A-49) contains the RRPs for storage/accumulation tanks with secondary containment. Once again, a comparison of these profiles with the corresponding baseline profiles reveals a marked reduction in total releases due to secondary containment, especially for the MRRPs. The total releases for the secondary containment MRRPs range from 0 m^3 to approximately 0.023 m^3, whereas the total releases for the baseline MRRPs range from 1.39 m^3 to 977 m^3.

SQG Tanks

The RRPs for the three secondary containment SQG runs are shown in Exhibit A-6 of the Appendix (pp. A-50 to A-53). Comparing these with the baseline SQG RRPs, it can be seen that secondary containment results in a definite reduction in releases, but a less dramatic one than that observed in the case of treatment and storage/accumulation tanks.

Total releases over the 20-year time horizon for the secondary containment MRRPs are zero in all cases, while total releases for the baseline MRRPs range from 0.38 m^3 (above-ground tank) to 1.96 m^3 (underground tank).

5.2.4 Other Regulatory Scenarios

In this section we provide a very brief discussion of the HWTF model results for the partial secondary containment with ground-water monitoring, corrosion protection, and leak-testing with ground-water monitoring scenarios. The summary results for these three scenarios are presented in their entirety in the Appendix to the report.

The frequencies of failure events under the partial secondary containment scenario are nearly identical to those under the baseline scenarios. This is due to the fact that partial secondary containment does not entail any changes in the tank itself but involves installing structures to contain releases and prevent them from reaching the environment.

In nearly all cases, partial secondary containment resulted in a substantial reduction in release volumes relative to the baseline scenario. However, the reduction was not as marked as with secondary containment. This may be a result of the inability of partial containment to prevent releases from the on-grade or in-ground portion of a tank. Thus, such releases may not be detected until they are detected by ground-water monitoring at the monitoring well.

The frequencies of failure events under the corrosion protection scenarios are virtually identical to those for the baseline scenario, with the exception of pipe and tank corrosion. The frequencies of these two events were far lower with corrosion protection. However, the release volumes for the RRPs under the corrosion protection scenarios were generally not smaller than those for the baseline scenario. This is due, in part, to the fact that corrosion protection alone does not reduce the frequency of many of the most important failure events, such as ruptures and overflows. These events can account for a very large portion of total releases. It is also important to note that we modeled corrosion protection without any form of leak detection.

The failure frequencies for the leak testing scenario also do not differ significantly from those for the baseline scenario. However, the total releases for the RRPs for this scenario are substantially smaller than those for the baseline scenario. But the releases are not as small as those for secondary containment. The implementation of leak testing does not prevent failures from occurring, nor does it prevent releases from contaminating the environment. However, if releases are eventually detected through either leak testing or ground-water monitoring, the leaking tank is removed, resulting in lower release volumes compared to the baseline scenario.

Although we do not discuss the HWTF model results for these regulatory approaches in detail, we present the risks associated with each alternative in the following section. Since the HWTF model results for each model tank is the only variable between regulatory scenarios, the detailed risk comparisons will directly reflect the HWTF model results under the alternative regulatory scenarios. The next section presents the risk estimates that were generated based on the representative release profiles discussed above and presented in the Appendix to the report.

5.3 RISK RESULTS

Based on the representative release profiles from the HWTF model, we constructed frequency distributions of dominant risk estimates for the 22 model tank technologies under the five regulatory scenarios considered in the analysis. To construct these distributions, we performed TRAM runs for each of the waste streams and generic hydrogeologic settings associated with a model tank technology. Each of the release profile-waste stream-hydrogeologic setting dominant risk estimates were weighted, and these weighted estimates were then used to construct a frequency distribution of dominant risk estimates for a particular tank technology.[9] An example distribution is illustrated in Exhibit 5-13. This hypothetical example illustrates that 40 percent of all underground, carbon steel, storage tanks are associated with a dominant risk estimate between 10^{-3} and 10^{-1}.

We derived the frequency distribution of dominant risk estimates for a particular combination of tank technology and regulatory scenario as follows:

- Generated risk estimates for each combination of chemicals in identified waste streams, hydrogeologic settings, and representative release profiles. This step resulted in approximately 1,294 risk estimates.[10]

- Determined dominant risk estimates for each combination of waste stream, hydrogeologic setting, and representative release profile. This step resulted in approximately 324 dominant risk estimates.

- Assigned weights to each dominant risk estimate. This weight represents the percentage of the tank population that handles the associated waste stream, is located in the associated hydrogeologic setting, and is represented by the representative release profile. The weight assigned to a dominant risk estimate for a partcular combination of waste stream, X, and hydrologic setting, Y, and representative release profile, Z, is the product of: (1) the percentage of the tank technology that handles waste stream X; (2) the percentage of the tank technology that is located in hydrogeologic setting Y; and (3) the percentage of the tank technology that has releases as indicated by representative release profile Z.

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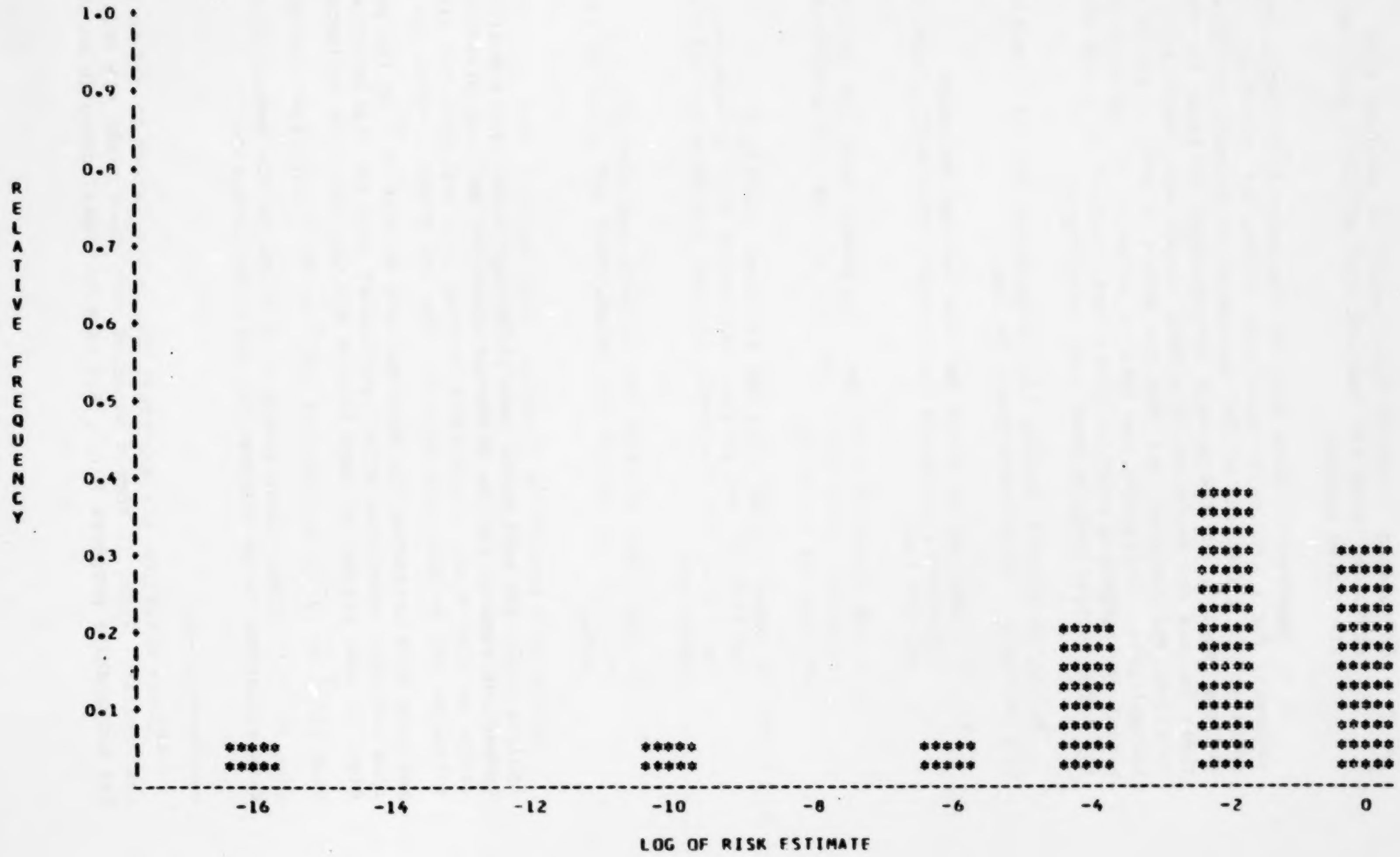
[9] To represent the risks for a particular waste stream, we chose the risk for the dominant chemical, rather than summing the risks for all chemicals in that waste stream. In addition, we did not differentiate between carcinogenic and non-carcinogenic risk estimates. Because we did not differentiate carcinogenic and non-carcinogenic risk estimates, we are evaluating both these health effects on an equal basis. For example, a situation with a dominant risk estimate of 10^{-3} with a carcinogenic effect is evaluated on the same scale as a dominant risk estimate of 10^{-3} with a non-carcinogenic effect. It is important to note that we did estimtae risk estimates fcr each chemical in a particular waste stream.

[10] Per technology there are approximately six waste streams, four constituents per waste stream, nine hydrogeologic settings and six representative release profiles.

EXHIBIT 5-13

HYPOTHETICAL FREQUENCY DISTRIBUTION OF
RISK ESTIMATES UNDERGROUND CARBON STEEL STORAGE
TANK (4,000 gal.) ALL FLOW FIELDS, ALL WASTE STREAMS



- Calculated frequency distribution of dominant risk estimates using the dominant risk estimates and their associated weights.

It is important to note that the frequency distribution of dominant risk estimates for a particular model tank technology (under any regulatory scenario) is a function of the representative release profiles, the waste streams handled, and the generic hydrogeologic settings for that tank. All of these factors are dependent on a tank's size, age, material of construction, location, and category, and thus are unique to each of the 22 model tank technologies. Therefore, the results presented in this section are mainly useful for comparing relative risks among regulatory scenarios, rather than for direct comparisons between tank technologies.

Below, we present several risk comparisons for the scenarios considered in this analysis. These comparisons include:

- A comparison of risks for baseline and secondary containment scenarios for storage, treatment, accumulation, and SQG tanks;
- A comparison of risks for underground tanks for baseline, secondary containment, and leak testing with ground-water monitoring scenarios;
- A comparison of risks for baseline, secondary containment, and partial containment with ground-water monitoring for treatment, storage, accumulation and SQG tanks; and
- A comparison of risks for baseline and corrosion protection scenarios for carbon steel and stainless steel tanks.

Rather than presenting frequency distributions, such as presented in Exhibit 5-13, for each model tank technology under each scenario, we have summarized results for the different scenarios and have presented them in bar graphs so that direct comparisons between risk estimates for different scenarios can be made more readily. The bar graphs present the percent of non-zero risk estimates (in this analysis we used 10^{-9} as the zero/non-zero risk cut-off) associated with a particular tank and regulatory scenario. Also, in some graphs, we have divided the non-zero risk estimates into low risk (10^{-9} to 10^{-5}), medium-risk (10^{-5} to 10^{-3}) and high-risk (greater than 10^{-3}).[11] Thus, these graphs also allow for the reduction in high risk situations to be compared for different scenarios.

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[11] These divisions are arbitrary and were selected to aid in presenting the results. Also, it should be noted that these risks are relative (i.e., for comparative purposes only), and have no significance in an absolute sense.

5.3.1 Comparison of Risks for Baseline and Secondary Containment Scenarios

To compare risks for existing hazardous waste tanks managed according to the baseline scenario to new tanks with full secondary containment and interstitial monitoring systems, we evaluated risks under each scenario for all of the 22 model tank technologies included in the analysis, and used these risk estimates to construct bar graphs comparing non-zero risk estimates for the two scenarios. These bar graphs are presented in Exhibits 5-14 through 5-17, for treatment, storage, accumulation, and SQG tanks, respectively.[12]

As illustrated, risk estimates were reduced significantly for all tanks, with a typical reduction of about 50 percent in non-zero risk estimates between baseline and secondary containment scenarios. More importantly, high risk situations (relative risks greater than 10^{-3}) were reduced by 80 percent or more for most tank technologies. Thus, from our analysis, we conclude that secondary containment systems, equipped with leak detection systems, are a very effective method of reducing the risks associated with hazardous waste tanks. Secondary containment systems prevent most releases from escaping to the environment, allowing hazardous wastes to be released only as a result of catastrophic events, hose ruptures and loose hose connections (for underground tanks), and cracking of concrete pads and berms.

Our risk analysis for these scenarios produced one unusual set of results. One tank technology, an in-ground, concrete, accumulation tank, was found to present zero risk under both the baseline and secondary containment scenarios. Although this tank stores relatively low-risk, dilute waste streams, we believe that this result is driven mainly by a lack of resolution within the HWTF model with regard to failure events for concrete tanks. Therefore, we consider this result, and the results of our analysis for all concrete tanks, to be very preliminary and subject to revision as we obtain better information. (This holds true not only for the baseline and secondary containment scenarios, but for all other scenarios as well.)

5.3.2 Comparison of Risks for Underground Tanks for Baseline, Secondary Containment, and Leak-Testing with Ground-Water Monitoring Scenarios

In Exhibit 5-18, we compare relative risks for underground carbon steel, stainless steel, and FRP tanks for the baseline, secondary containment, and leak-testing with ground-water monitoring scenarios. As illustrated, leak testing with ground-water monitoring, while reducing risks for underground tanks compared to the baseline scenario, is not nearly as effective as secondary containment in reducing risks associated with these tanks.

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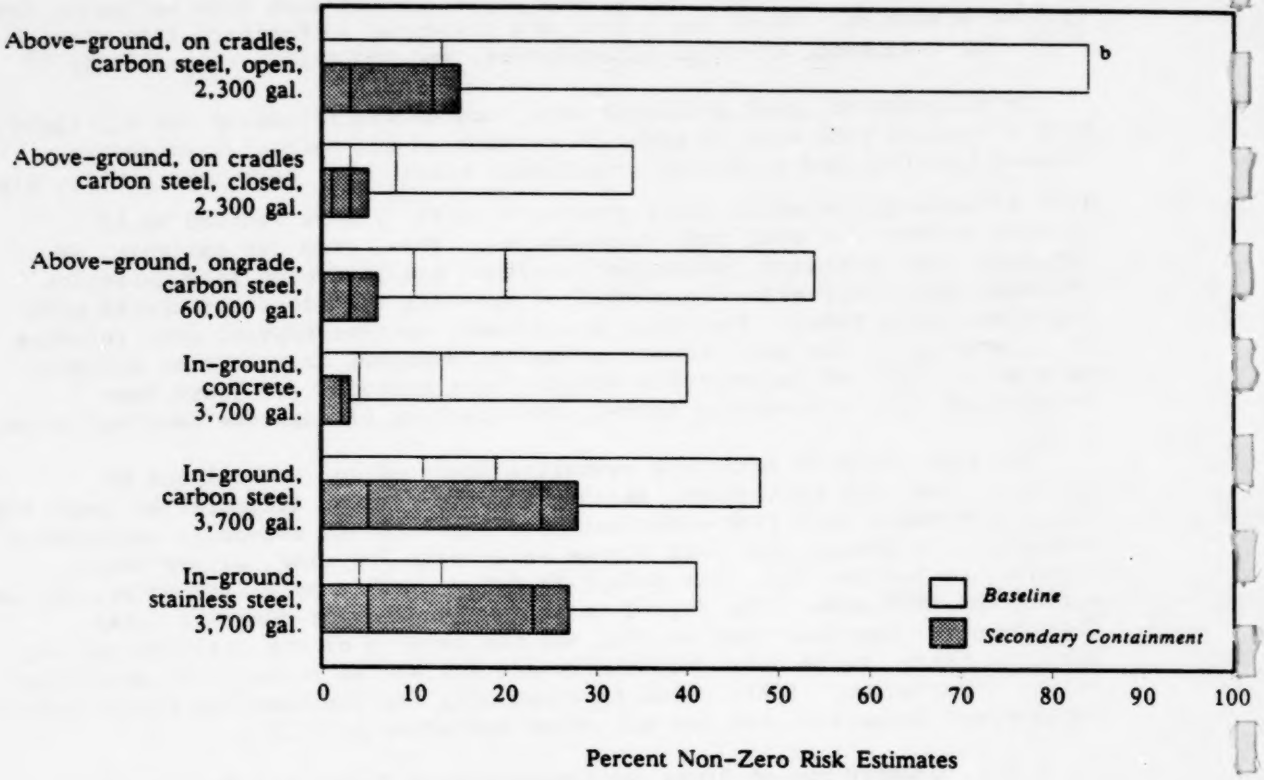
[12] These exhibits present the percent of risk estimates categorized as low, medium, and high-risk situations. For example, as illustrated in Exhibit 5-14, for an above-ground, ongrade, carbon steel tank approximately 10, 10 and 35 percent of the risk estimates are low, medium and high-risk, respectively.

EXHIBIT 5-14

COMPARISON OF RISKS FOR BASELINE AND SECONDARY CONTAINMENT SCENARIOS[a]

TREATMENT TANKS



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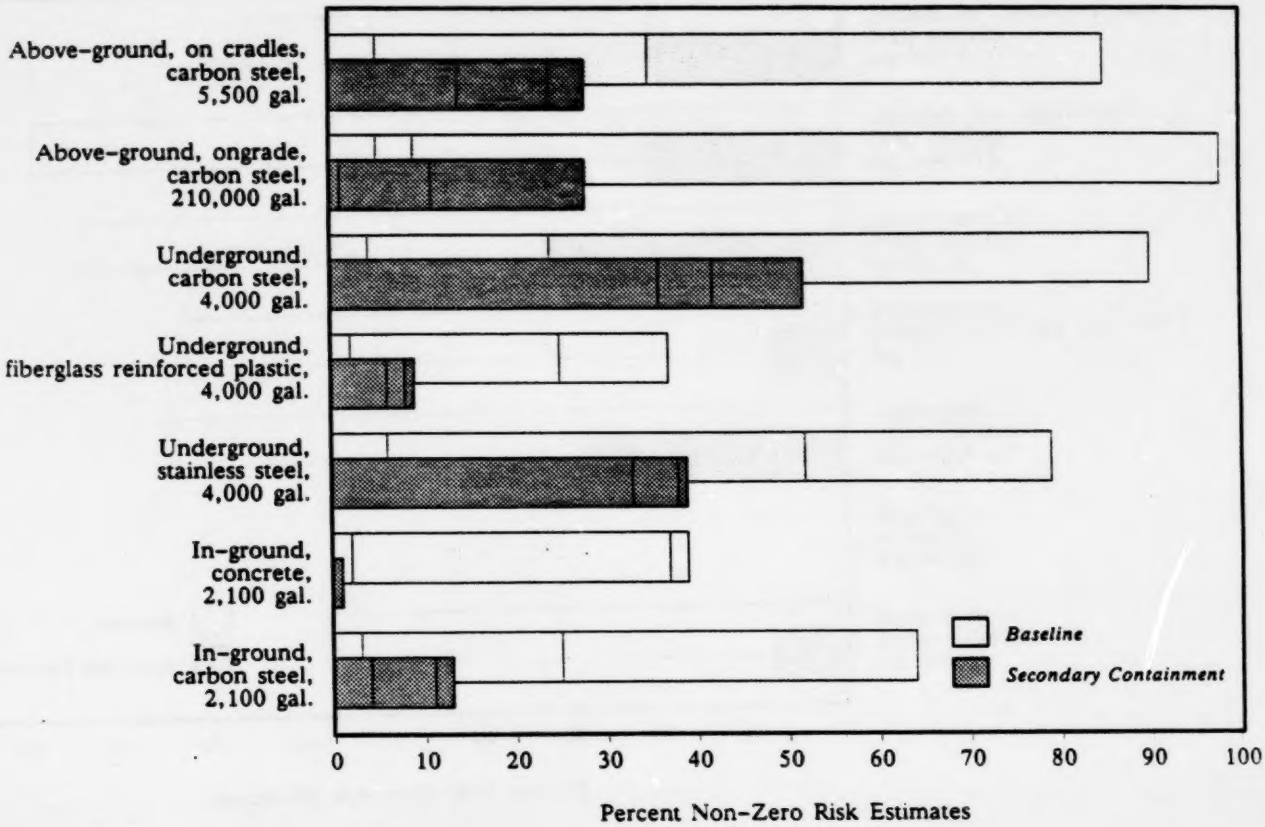
[a] Lines on bars represent cut-off between arbitrarily selected low, medium, and high risk categories.

[b] For this technology, 13 and 71 percent of the risk estimates are medium and high risk, respectively.

EXHIBIT 5-15

COMPARISON OF RISKS FOR BASELINE AND SECONDARY CONTAINMENT SCENARIOS[a]

STORAGE TANKS



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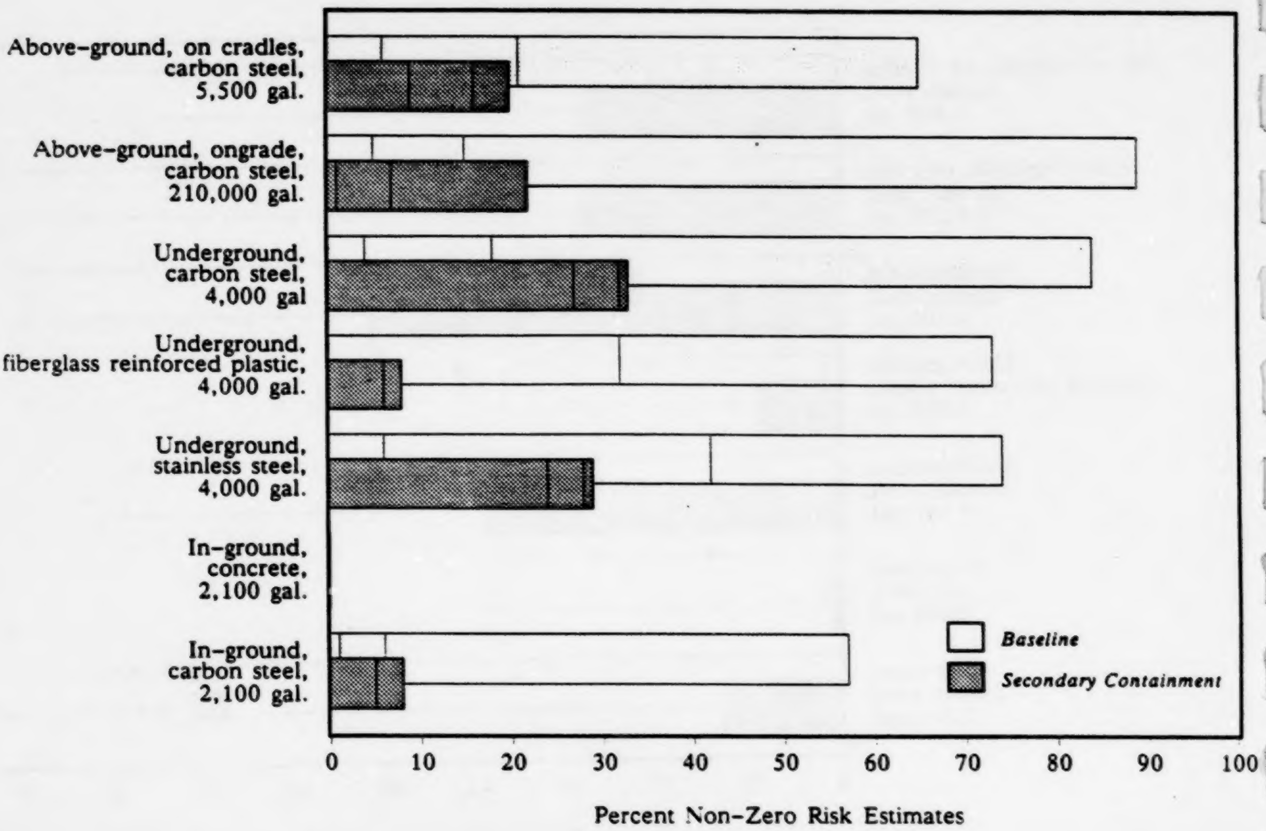
[a] Lines on bars represent cut-off between arbitrarily selected low, medium, and high risk categories.

EXHIBIT 5-16

COMPARISON OF RISKS FOR BASELINE AND SECONDARY CONTAINMENT SCENARIOS[a] ACCUMULATION TANKS



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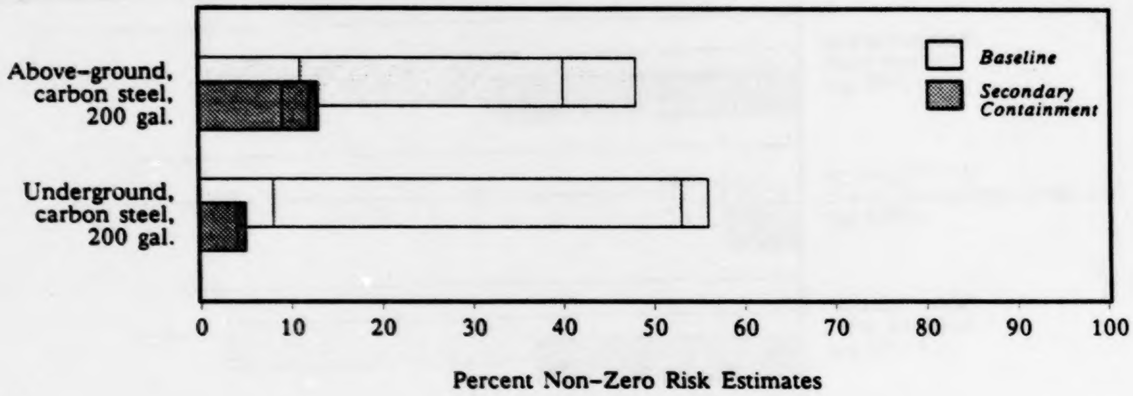
[a] Lines on bars represent cut-off between arbitrarily selected low, medium, and high risk categories.

EXHIBIT 5-17

COMPARISON OF RISKS FOR BASELINE AND SECONDARY CONTAINMENT SCENARIOS[a]

SMALL QUANTITY GENERATOR TANKS



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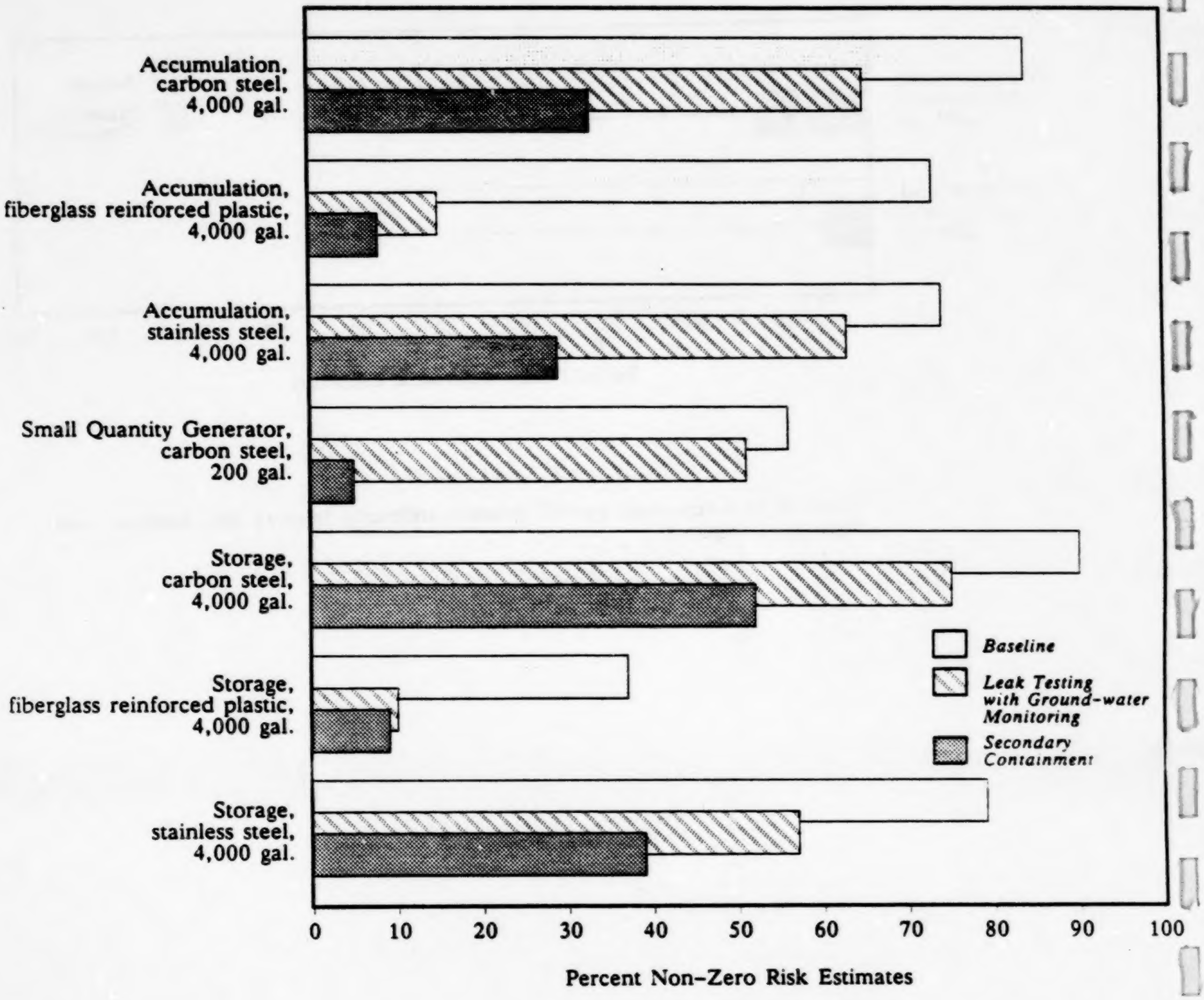
[a] Lines on bars represent cut-off between arbitrarily selected low, medium, and high risk categories.

EXHIBIT 5-18

COMPARISON OF RISKS FOR BASELINE, SECONDARY CONTAINMENT AND LEAK TESTING WITH GROUND-WATER MONITORING SCENARIOS

UNDERGROUND TANKS



Our leak testing and ground-water monitoring scenario assumes that leak tests are performed semi-annually, using a hydrostatic pressure test that is capable of detecting leaks of $3.8 \times 10^{-4} m^3$ (0.1 gallons) per hour. Ground-water monitoring is provided by wells located 10 meters downgradient, and contamination is assumed to be detected as soon as the concentration of any chemical stored in the tank exceeds a detectable concentration at the monitoring well. The tank is considered to be removed upon detection of a leak and all subsequent releases are set to zero.[13]

Thus, our results for leak testing and ground-water monitoring are somewhat driven by our assumptions. However, we believe that both of the assumptions mentioned above are reasonable, and that our results illustrate several real problems that limit the effectiveness of leak testing with ground-water monitoring. The two major problems are:

- **Leak testing is not effective in detecting small leaks.** A leak of 0.0001 m^3/hour seems trivial, but considering the highly concentrated nature of some wastes stored in underground tanks, such an amount may present significant risks to human health. For example, a tank leaking at 0.0001 m^3/hour will release approximately 1 m^3 (264 gallons) of hazardous waste over a year. If this waste contains 10 percent benzene,[14] the relative lifetime risk to an individual using ground water contaminated by this leak may be as high as 10^{-4}.

- **Ground-water monitoring is limited in its effectiveness in detecting releases of contaminants from hazardous waste tanks.** For highly mobile contaminants in hydrogeologic settings where horizontal ground-water velocities are rapid and unsaturated zone depths are small, detection of releases by ground-water monitoring is relatively rapid, and thus quick action may be taken to prevent further contamination. However, for less mobile contaminants and/or hydrogeologic settings with slow horizontal ground-water velocities or deep unsaturated zones, detection times may be on the order of years or tens of years. This allows for the release of relatively large volumes of hazardous waste before detection, thus presenting very significant human health risks or requiring extensive corrective action.[15]

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[13] Because we assume that the tank is removed (instead of replaced) and subsequent release volumes are set to zero, the distribution of risk estimates represents a lower bound of nonzero risk estimates. In actuality, the tank is likely to be replaced and future releases may occur. For this study, we did not model tank replacement (following detection by ground-water monitoring) because we used two different models to model detection and releases. TRAM is used to model subsurface transport and detection, and HWTF is used to model releases. We could not integrate the results from both models within a reasonable framework.

[14] Benzene is a common constituent of many hazardous waste streams. It is a carcinogen and is moderately mobile in the subsurface environment relative to other hazardous organic chemicals.

The combined protective measures of leak testing and ground-water monitoring somewhat counteract these effects; for example, a leak too small to be detected by leak testing may be detected by ground-water monitoring, and a release of a low-mobility contaminant may be detected quickly if the leak is large enough to be detected by a semi-annual leak test. However, small leaks of low-mobility, highly toxic, persistent chemicals (e.g., lindane) in low velocity ground-water settings may go undetected for long periods of time, and may eventually present substantial health risks to individuals using ground water as a source of drinking water.

Finally, although we do not generally consider the results of our analysis to be appropriate for comparisons between tanks, it is interesting to note the difference in the effectiveness of leak testing with ground-water monitoring between steel and FRP tanks. As illustrated, leak testing with ground-water monitoring is much more effective in reducing risks for FRP tanks than for steel tanks. We believe that this may be due to differences in failure mechanisms for the two tank materials; steel tanks may develop small leaks due to corrosion that are undetectable by leak testing, whereas FRP tank failures are generally large seam cracks or ruptures that would generally be detected by leak testing. Thus, these results indicate that for FRP tanks, leak testing with ground-water monitoring is nearly as effective as secondary containment. However, due to the fact that leak testing with ground-wter monitoring represents lower-bound estimates (see footnote 13), these results should be viewed with caution.

5.3.3 Comparison of Risks for Baseline, Secondary Containment and Partial Containment With Ground-Water Monitoring

Risks for baseline, secondary containment, and partial containment with ground-water monitoring are compared for on-grade and in-ground treatment tanks and for storage and accumulation tanks in Exhibits 5-19 and 5-20, respectively. Our results indicate that partial containment with ground-water monitoring is effective in reducing risks for hazardous waste tanks, but in general does not reduce risks as greatly as does the installation of full secondary containment systems.

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[15] In our analysis, we did not consider corrective action (i.e., contaminated soil excavation and/or ground-water treatment) for tanks. Upon detection, we assumed only that the tank was removed, preventing further releases.

EXHIBIT 5-19

COMPARISON OF RISKS FOR BASELINE, SECONDARY CONTAINMENT AND PARTIAL SECONDARY CONTAINMENT WITH GROUND-WATER MONITORING SCENARIOS

TREATMENT TANKS

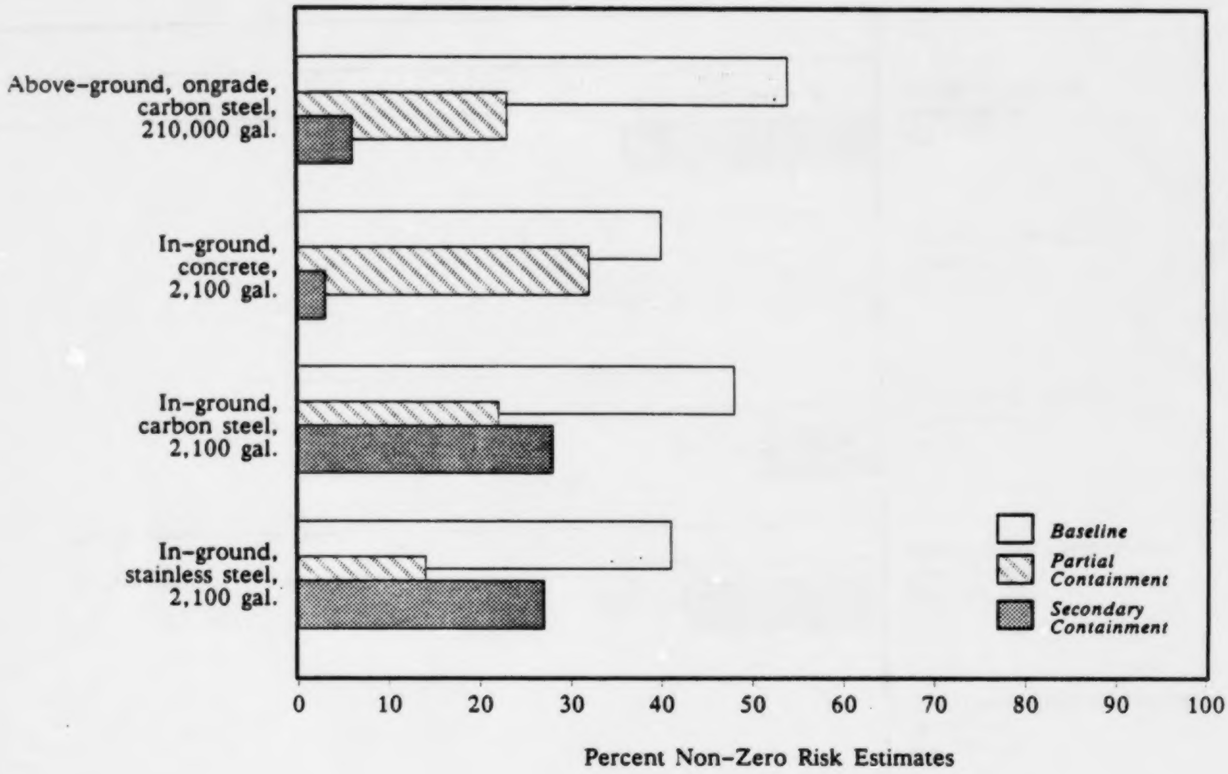
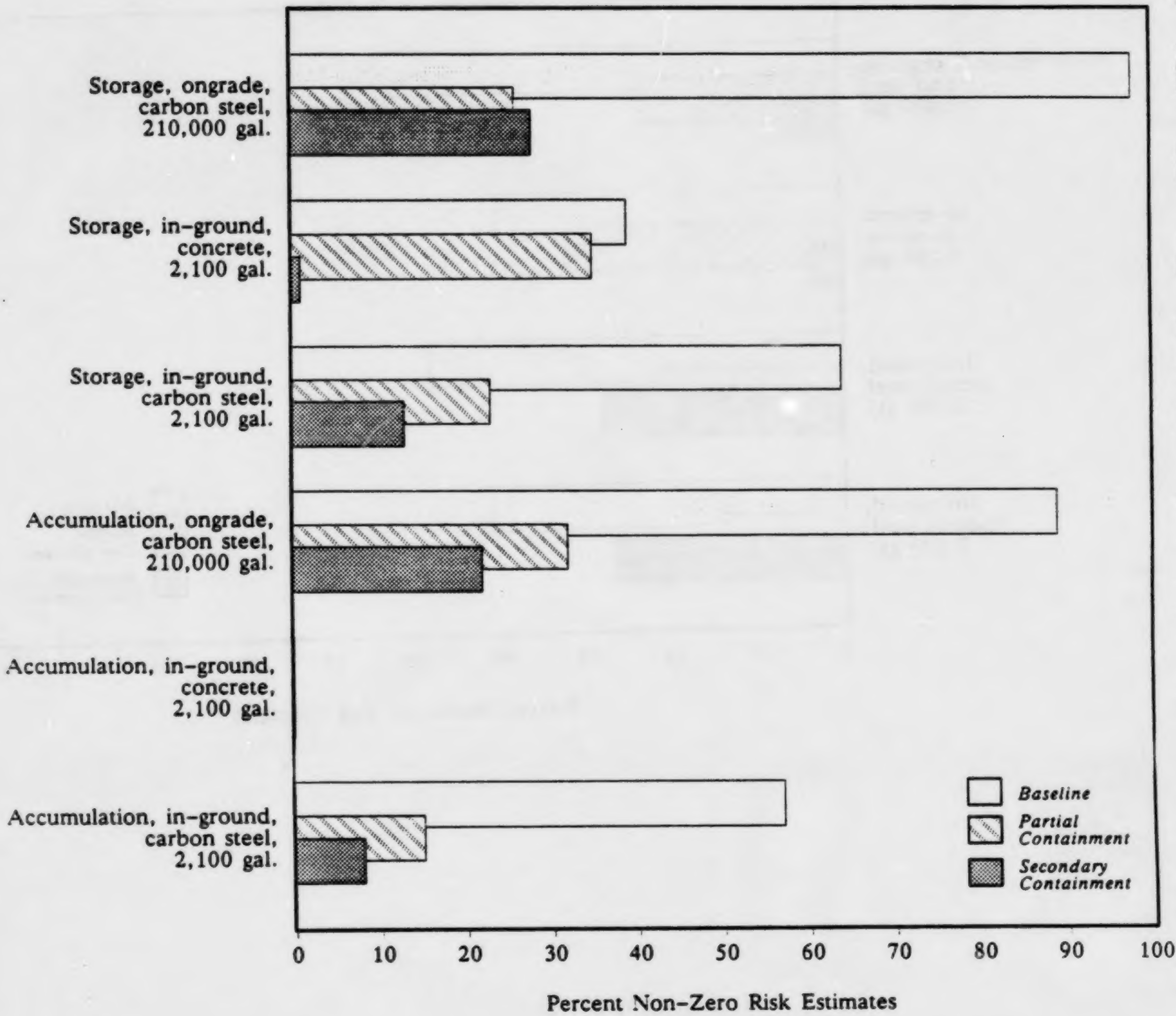


EXHIBIT 5-20

COMPARISON OF RISKS FOR BASELINE, SECONDARY CONTAINMENT AND PARTIAL SECONDARY CONTAINMENT WITH GROUND-WATER MONITORING SCENARIOS

STORAGE/ACCUMULATION TANKS



As noted earlier, partial containment prevents releases only from the above-ground portions of hazardous waste tanks and ancillary equipment. Ground-water monitoring is therefore necessary to detect leaks from in-ground or ongrade portions of these tanks. Thus, the assumptions and limitations with respect to ground-water monitoring that were mentioned in the previous section also apply to this scenario. Leaks are assumed to be detected when the detectable concentration of any contaminant is exceeded at the monitoring well. Time to detection is a function of the liquid volume flux from the tank, the mobility of the contaminant(s) of concern, and the horizontal ground-water velocity and depth of the unsaturated zone[16] for the hydrogeologic setting in which the tank is located. Once again, we assume no corrective action, only that the tank is removed upon detection of a leak and all release volumes for the remaining years of the 20-year time horizon are set to zero.[17]

For some tanks presented in Exhibits 5-19 and 5-20, partial containment with ground-water monitoring appears to be more effective than secondary containment in reducing relative risks. These results are counter-intuitive in that it is difficult to understand how a system in which releases to the environment must occur in order to facilitate leak detection could be more effective than a system that prevents releases under all but the most extreme circumstances. The differences in risk reduction are minor, however, and may be due in part to our assumptions regarding detection and tank removal, in which all subsequent releases are set to zero. (The underlying assumption is that a tank is no longer operated at that site, thus biasing the results toward partial containment and ground-water monitoring.) Conversely, tanks with full secondary containment are modeled to operate over the entire 20-year time horizon and may release contaminants over the entire modeling period. This assumption may result in greater release volumes for secondary containment than for partial containment over the 20-year modeling period, and, therefore, may affect the results of the risk analyses. Also, these results may be due to a lack of resolution within the HWTF model with regard to the modeling of certain secondary containment systems. We are conducting further analyses in this area.

5.3.4 Comparison of Risks for Baseline and Corrosion Protection Scenarios

In Exhibit 5-21, we compare frequency distributions of risk estimates for the baseline and corrosion protection scenarios. Corrosion protection was considered to be applicable to any metal (i.e., carbon steel and stainless steel) tank system in which the tank or ancillary equipment is in contact with the soil (e.g., above-ground, ongrade tanks; in-ground tanks; and underground

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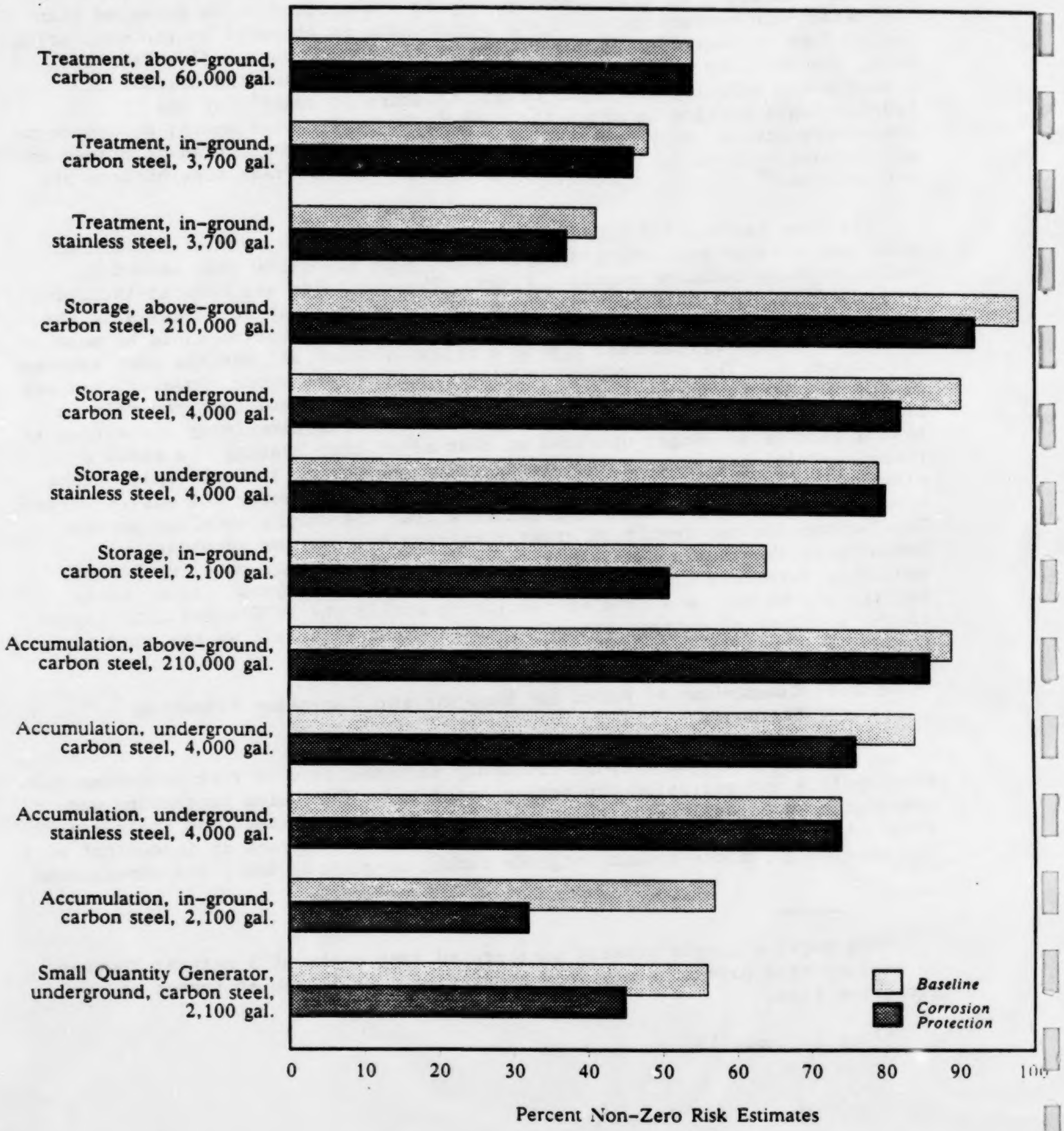
[16] We model a single generic unsaturated zone depth of 5 meters; however, in reality this parameter may vary greatly, and will have an impact on detection time.

[17] See footnote 13.

EXHIBIT 5-21

COMPARISON OF RISKS FOR BASELINE AND CORROSION PROTECTION SCENARIOS

CARBON STEEL AND STAINLESS STEEL TANKS



tanks). Corrosion protection was assumed to be provided by cathodic protection (i.e., impressed current).

As illustrated in Exhibit 5-21, our results indicate that corrosion protection is not very effective in reducing the risks associated with hazardous waste tanks, and overall risk reduction may be considered negligible for this regulatory scenario. This neglible reduction is, in part, due to the fact that corrosion protection does not aid in preventing many of the failure events associated with hazardous waste tanks, such as seam cracks, and overflows. Also, for this regulatory scenario we have assumed no method for the detection of releases (e.g., no leak testing or ground-water monitoring) once they occur. Finally, it should be noted that the effectiveness of corrosion protection may depend on site-specific soil parameters, and it is difficult to include such site-specific data in an analysis of this sort. Thus, assumptions within our model (e.g., our use of a benign rather than an aggressive soil to represent site soil conditions) may cause us to under-estimate the effectiveness of corrosion protection.

5.3.5 Summary and Conclusions

Based on the results of the risk analysis, we have ranked the regulatory scenarios in descending order of risk reduction from the baseline as follows:

- Secondary Containment for all tanks;
- Partial Containment and Ground-Water Monitoring for ongrade and in-ground tanks;
- Leak Testing and Ground-Water Monitoring for underground tanks; and
- Corrosion Protection for carbon steel and stainless steels tanks in contact with soil.

It is important to note that direct comparisons cannot be made between all scenarios (for example, partial containment and leak testing scenarios apply to completely different tank groups); however, the above ranking is an overall indication of the effectiveness of the different scenarios in reducing risks compared to baseline.

Thus, our results indicate that EPA's proposed requirements for full secondary containment is an effective strategy for preventing environmental damage caused by leaking hazardous waste tanks. For in-ground and ongrade tanks, the partial containment with ground-water monitoring is, in most cases, significantly less effective than full secondary containment. For underground tanks, leak testing with ground-water monitoring does not appear to be nearly as effective as full secondary containment. Finally, corrosion protection, without any detection options, does not appear to be very effective in reducing the risks presented by carbon steel and stainless steel tanks.

5.4 COMPARISON OF RISK ESTIMATES FOR HYDROGEOLOGIC SETTINGS AND WASTE STREAMS

The risk estimates developed in this analysis are not only a function of tank failure events and release volumes, but are also controlled by the waste streams stored in a particular tank and the hydrogeologic settings in which the tank is located. In considering regulatory alternatives for tanks, such as a risk-based variance to secondary containment requirements, it would be very important to consider these variables on a site-specific basis.

Our analysis was not designed to compare these factors, but rather was constructed to obtain comparative risk results for different regulatory scenarios. However, by comparing the generic flow fields and waste streams included in our analysis, some insight may be gained into what hydrogeologic and waste parameters most greatly influence risk. Below, we briefly discuss the effects of these parameters on our analysis.

5.4.1 Comparison of Ground-Water Flow Fields

TRAM uses nine generic ground-water flow fields to approximate the range of hydrogeologic settings encountered across the U.S. In order to compare the relative risks for tanks located in these different environments, we evaluated risks under the baseline scenario for all nine flow fields for a single tank technology, an underground carbon steel storage tank, and two waste streams, F003 (spent non-halogenated solvents, containing benzene, methyl ketone, and four other solvents) and F001 (spent halogenated solvents, containing carbon tetrachloride, trichloroethylene, and several other chlorinated compounds). Differences in risks among ground-water scenarios depend on complex interactions between contaminant mobility and persistence, ground-water dilution and dispersion, and the presence of non-aquifer layers.

From similar Liner Location Risk and Cost Analysis Model analyses we have determined that comparisons using waste streams with highly mobile, highly persistent constituents (such as F003) show a different distribution of risks for the nine generic flow fields than waste streams with less mobile, less persistent constituents (such as F001). Therefore, two waste streams were chosen to account for differences in contaminant mobility and persistence that may affect comparisons between different ground-water scenarios. For comparative purposes, we used an exposure well distance of 60 meters.

Risks for each ground-water scenario were determined for the selected model tank technology and waste streams F003 and F001, and are summarized in Exhibits 5-22 and 5-23. As illustrated, risks are distributed from 1 to 10^{-6} for ground-water flow fields A through I for waste stream F003, and from 10^{-2} to 10^{-10} for waste stream F001. The highly mobile, highly persistent chemicals in waste stream F003 result in the highest risk being exhibited by flow field A, which has the slowest ground-water velocity of any of the nine settings (1 m/year). This result is due to two factors: (1) the slow ground-water velocity in flow field A results in minimal dilution, thus causing well concentrations of contaminants to be very high; and (2) the slow

EXHIBIT 5-22

COMPARISON OF RISKS FOR HYDROGEOLOGIC SETTINGS
FREQUENCY DISTRIBUTION OF RISK ESTIMATES FOR UNDERGROUND CARBON
STEEL STORAGE TANK (4,000 GAL) ALL FLOW FIELDS, WASTE STREAM F003

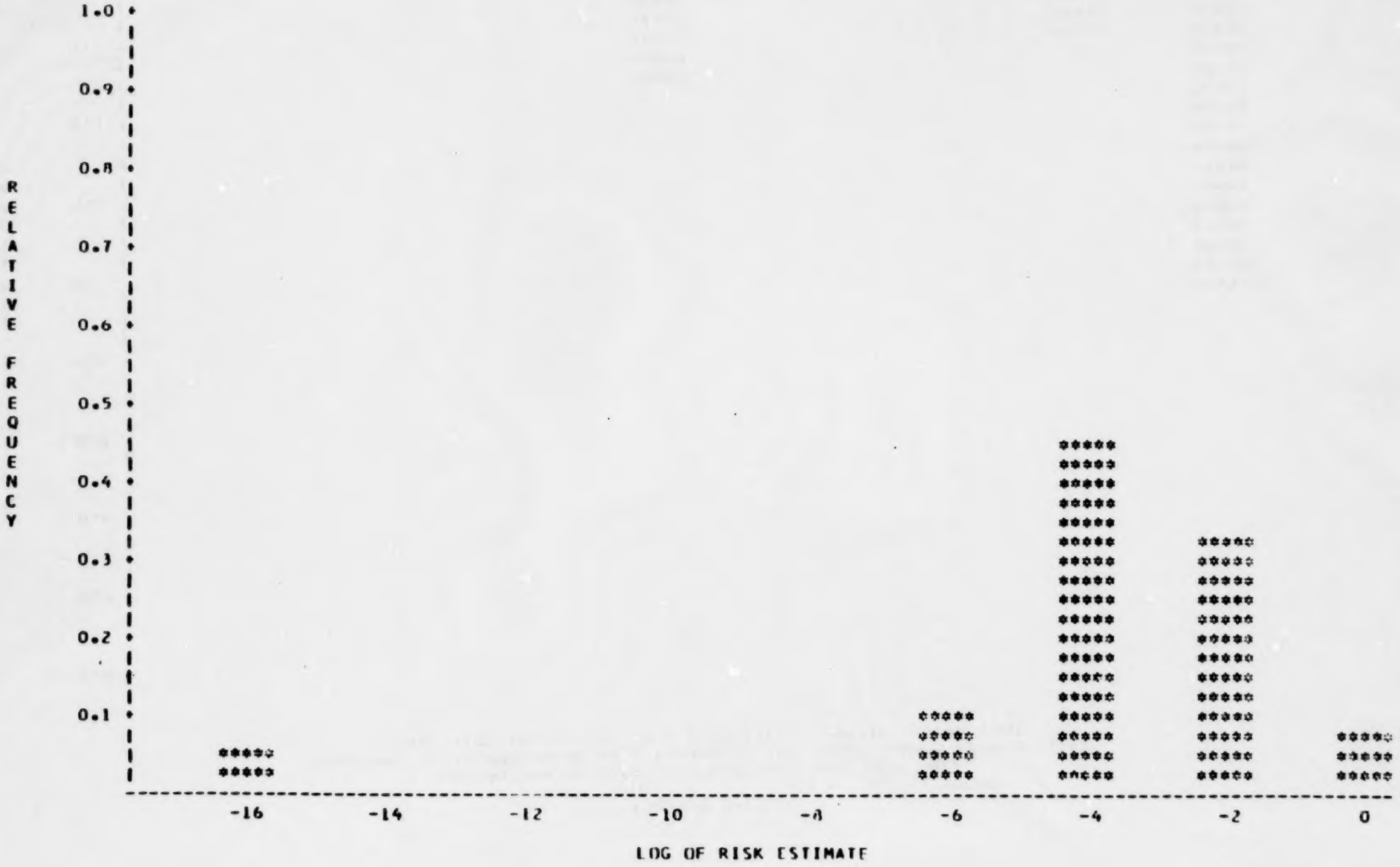
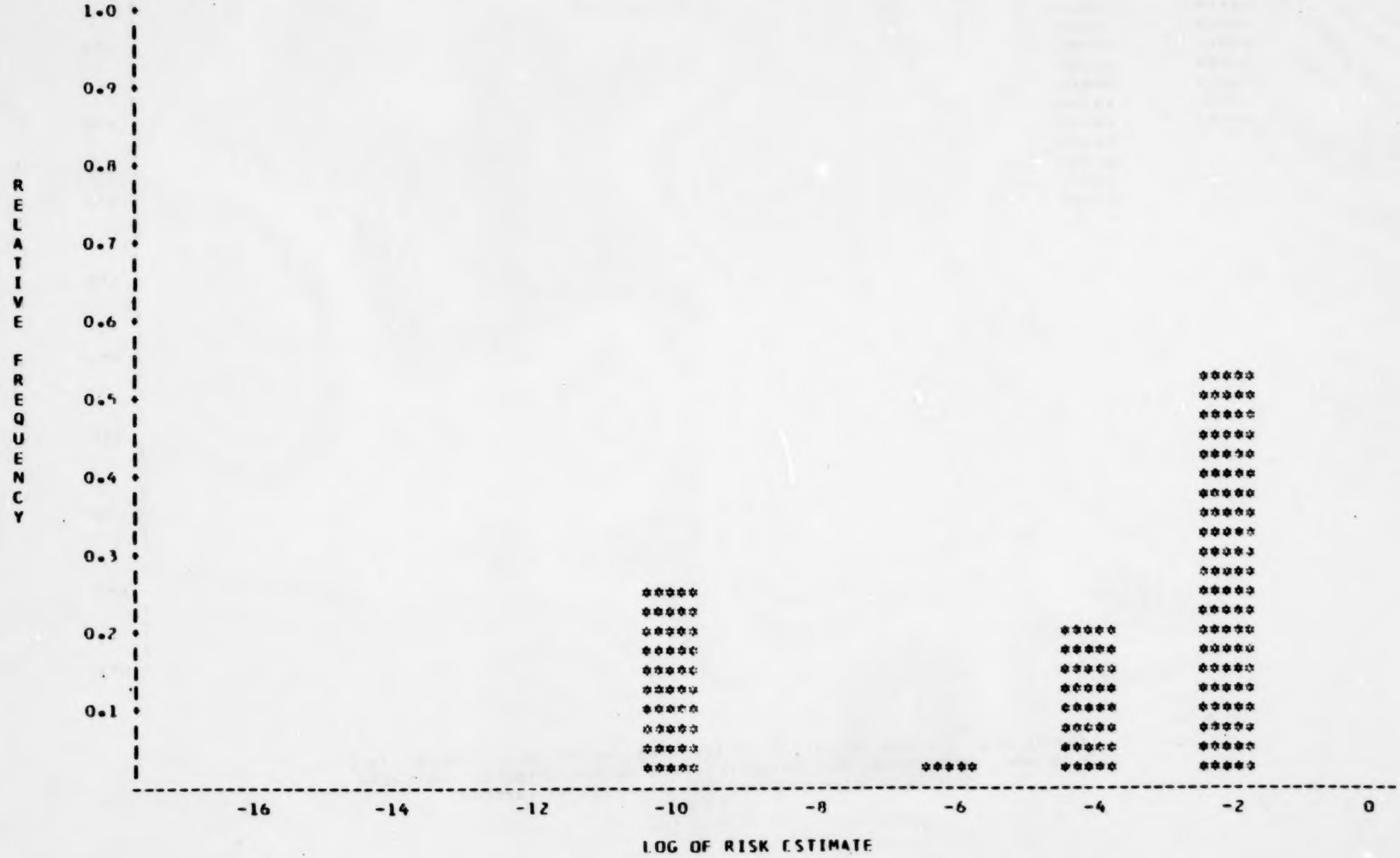


EXHIBIT 5-23

COMPARISON OF RISKS FOR HYDROGEOLOGIC SETTINGS
FREQUENCY DISTRIBUTION OF RISK ESTIMATES FOR UNDERGROUND, CARBON STEEL
STORAGE TANK (4,000 GAL) ALL FLOW FIELDS, WASTE STREAM F001



ground-water velocity also results in the longest exposure period (e.g., persons served by wells in flow field A have an average exposure period of 200 years, as opposed to flow field B, with an average exposure period of 140 years, and flow field E with an average exposure period of 16 years.) Therefore two waste streams were chosen to account for differences in contaminant mobility and persistence that may affect comparisons between different ground-water scenarios.

Other high-risk flow fields are B, H, and I, while lowest-risk flow fields are E and F. It should be noted, however, that these results are a function of both the distance to the exposure point (distance from source to well) and the choice of the time horizon over which risk is considered. For example, if a well distance of 1500 meters and a 200-year time horizon were chosen, a flow field with a moderately ground-water velocity (e.g., flow field C; 100 meters/year) would appear to present greater risks than flow field A, because the containments being transported in flow field A may not reach the 1500 meter well within the 200-year time horizon.

Results for waste stream F001 are somewhat different, in that flow field A exhibits the lowest risk. This result is due to the lower mobility of F001 constituents, which results in only a small portion of the contaminant mass that is released by the tank reaching the 60 meter well by year 400, the final year we are considering in our analysis. Due to slightly greater ground-water velocity, contaminants do reach the 60 meter well in flow fields B, G and I, which are the highest-risk flow fields for waste stream F001. Once again, flow fields E and F present the lowest risks; this result is due to the rapid ground-water velocity in flow field E (resulting in more dilution and dispersion and a shorter period of exposure) and the presence of a non-aquifer overlying the affected aquifer in flow field F. (The presence of the non-aquifer layer greatly inhibits the movement of contaminants in this flow field.)

Thus, this analysis indicates that, for the 60 meter well distance, hydrogeologic settings with slower ground-water velocities present higher risks[18] in most cases than hydrogeologic settings with more rapid velocities. However, it is important to note that; (1) well distance greatly influences the results of this analysis; and (2) the analysis does not account for the amount of ground-water contaminated in each flow field, or the proximity of the hazardous waste tanks to ground-water users. For example, even highly mobile contaminants do not reach wells at 1,500 meters in flow field A, and therefore one would expect risks for this well distance to be dominated by flow fields, where velocities are sufficient to allow for some exposure. Also, while high ground-water velocity flow fields present the lowest risk, in our analysis, contamination in these aquifers will also result in the largest volume of contaminated ground water, which translates into greater probability of eventual exposure, more resource loss, and much greater clean-up costs.

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[18] Our analysis uses as the measure of risk, the 400-year average individual lifetime risk. A different risk measure (e.g., 200-year average individual lifetime risk) might produce somewhat different results.

Therefore, we conclude from our analysis that the effect of hydrogeologic setting on the risks presented by hazardous waste tanks is dependent not only on properties of the underlying aquifer but also on waste stream characteristics and local ground-water use considerations. For a risk-based variance approach, the interactions between these parameters would need to be considered on a site-specific basis.

5.4.2 Comparison of Waste Streams

Ideally, in comparing risks for different waste streams, a single comparison would be made across all waste streams for a single tank technology and a hydrogeologic setting. However, because different tank categories handle different groups of waste streams (e.g., SQG wastes differ significantly from treatment tank wastes), it is not possible to use our results to make a broad comparison of all the different waste streams included in the analysis. Also, comparisons among different waste streams within a particular tank category were complicated by differences in release volumes for the tank technologies within that category. Therefore, in order to make a direct comparison of waste streams within a particular category (i.e., identify high-risk and low-risk waste streams), we selected one tank technology from that category and compared risks for all wastes handled by that technology. By choosing tank technologies that handle a large number of waste streams, we were able to make direct comparisons among essentially all waste streams within each of the four major tank categories. Hydrogeologic setting was held constant by using risk results for flow field C in all cases.

Below, we present these comparisons for each tank category.

Treatment Tank Waste Streams. For a comparison among the different organic wastes treated in tanks, we selected an above-ground, on cradle, carbon steel, distillation tank system. Based on our initial waste stream analysis, it was determined that this tank technology handled six waste streams: F001, spent halogenated solvents; D001, ignitable wastes, N.O.S.; X907, chlorinated pesticide still bottoms; F003, spent non-halogenated solvents; U080, dichloromethane; and U226, 1,1,1-trichloroethane. Risks were calculated for each of these waste streams, and are summarized in Exhibit 5-24.

As illustrated, risk estimates for the various waste streams treated by this tank technology range from 1 to 10^{-4}. The highest risk estimates are exhibited by waste stream D001, ignitable wastes, N.O.S. Low-risk waste streams included U080, dichloromethane, and U226, 1,1,1-trichloroethane. Both of these contaminants are assumed to degrade fairly rapidly in ground-water-soil environments.

Another treatment tank technology, an above-ground, on-grade, carbon steel oxidation/reduction/precipitation (ORP) tank was selected in order to compare aqueous waste streams treated in tanks (heavy metals, reactive wastes, etc.). Ten waste streams were included in this comparison. The frequency distribution of risk estimates for the ten waste streams handled in this ORP tank is summarized in Exhibit 5-25. Due to the very large release volumes associated

EXHIBIT 5-24

COMPARISON OF RISKS FOR WASTE STREAMS ABOVE-GROUND, ON CRADLE, CARBON STEEL DISTILLATION TANK (2,300 GAL) FLOWFIELD C, ALL WASTE STREAMS

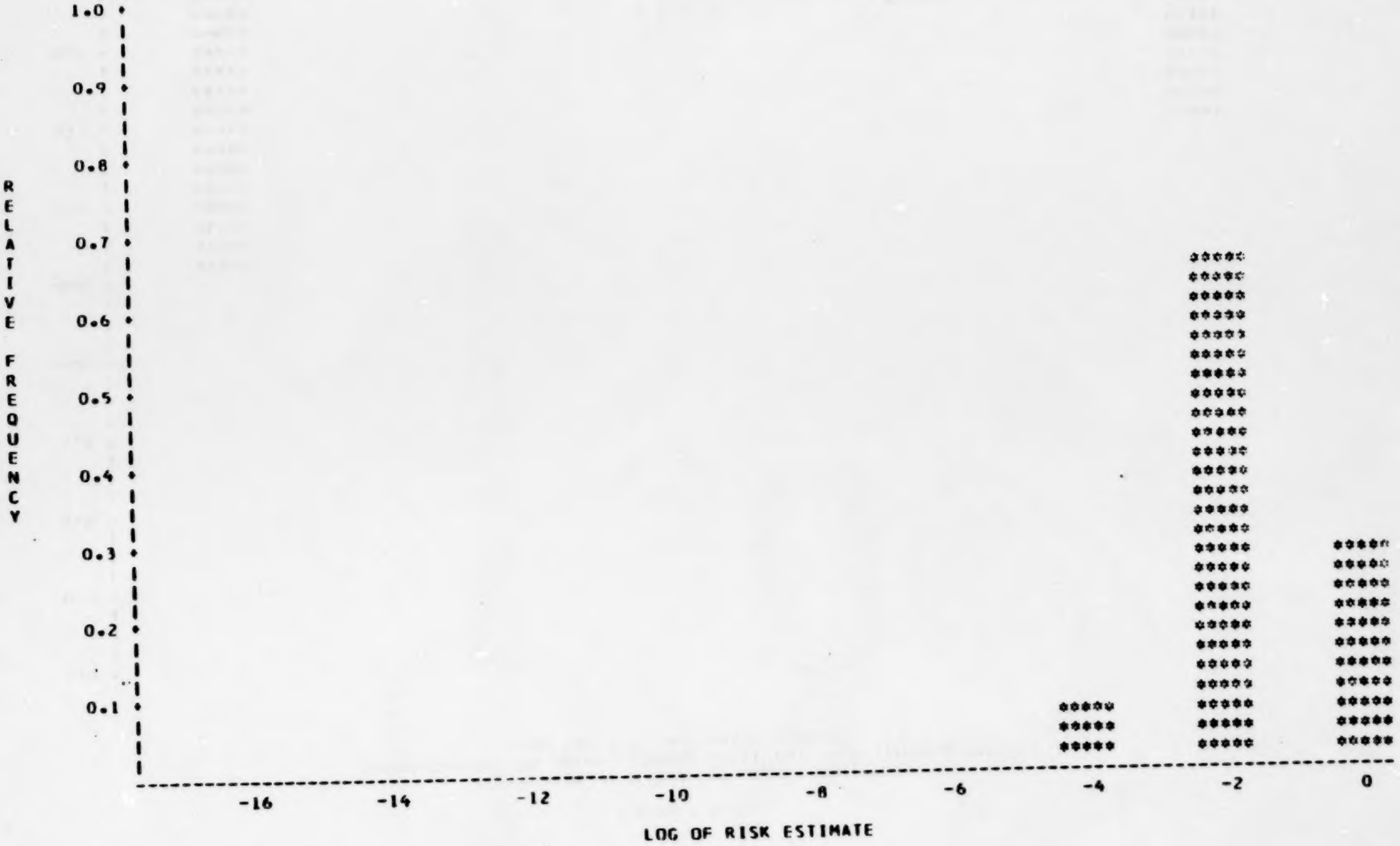
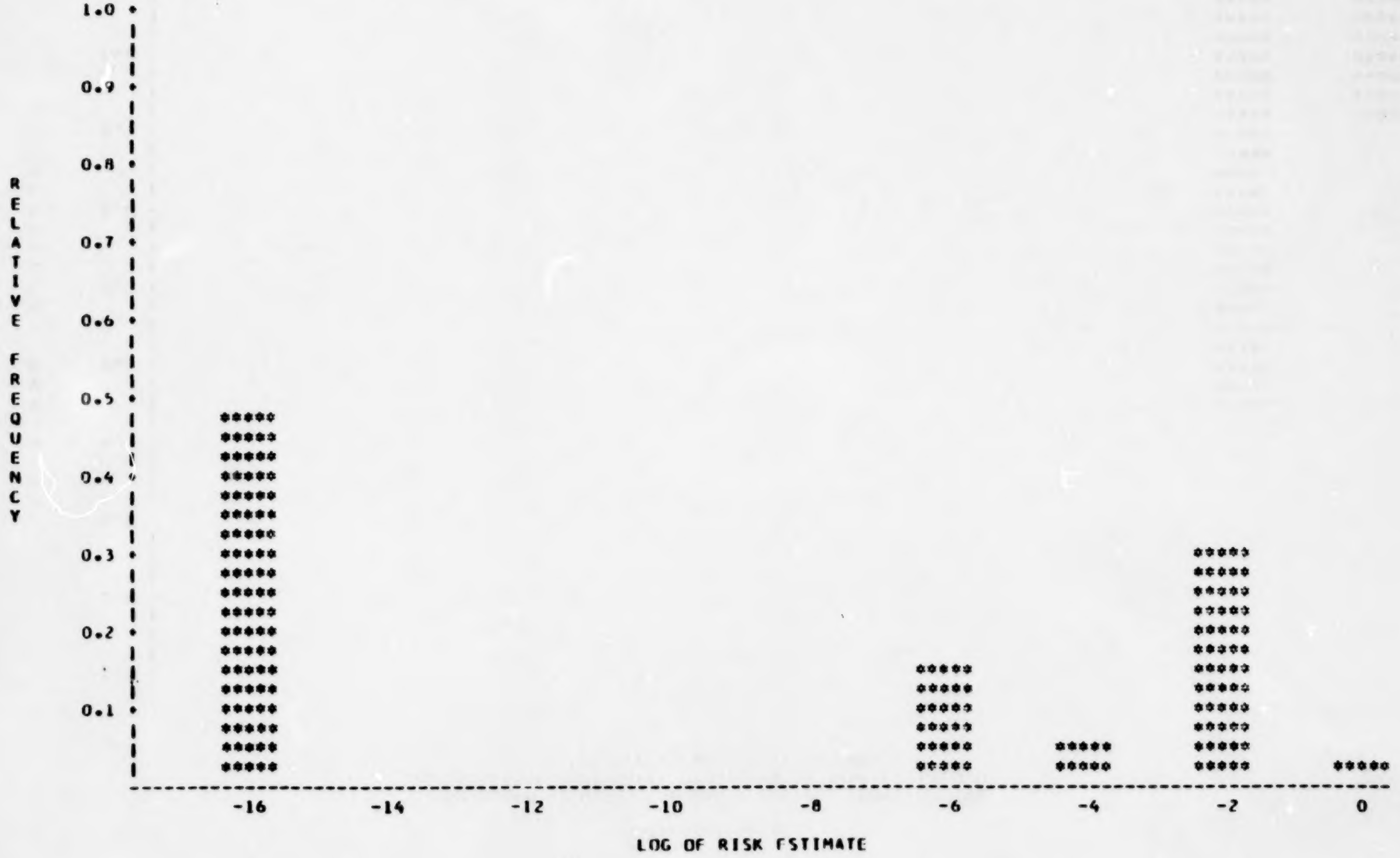


EXHIBIT 5-25

COMPARISON OF RISKS FOR WASTE STREAMS
ABOVE-GROUND, ON GRADE, CARBON STEEL ORP TANK (60,000 GAL)
FLOW FIELD C, ALL WASTE STREAMS



with the selected technology, dose-response thresholds for essentially all waste stream constituents were exceeded by a wide margin, and risks are very high for all wastes. However, particularly high risks are presented by waste streams P115, thallium sulfate (a low-mobility but very toxic metal), D004 (arsenic, a highly mobile and potent carcinogen), and D003 (reactive wastes, N.O.S.). Low-risk waste streams included K062, spent pickle liquor, and F007, electroplating wastes. Both of these low-risk waste streams are relatively dilute, with concentrations of lead and chromium in the low parts per million range.

Storage and Accumulation Tank Waste Streams. For a comparison of the waste streams handled in storage and accumulation tanks, we analyzed above-ground, on grade carbon steel storage tanks. Because release volumes are identical for storage and accumulation tanks, and the types of waste streams handled are very similar, we used this comparison to represent waste streams for both tank categories.

Twenty-one waste streams were selected for this technology. Once again, due to high release volumes, risks are relatively high for all waste streams (Exhibit 5-26). Waste streams with especially high risks included U188, phenol (a highly mobile and very common organic chemical); P115, thallium sulfate; D001, ignitable wastes, N.O.S.; and D003, reactive wastes, N.O.S. Once again, low risk waste streams included readily degradable chlorinated solvents such as U080, dichloromethane, and dilute aqueous wastes such as K048, petroleum refining wastes, and K062, spent pickle liquor.

SQG Waste Streams. Our final waste stream comparison was made among the nine wastes handled in SQG underground, carbon steel tanks. Waste streams for this technology included pesticide wastes, spent solvents, wood preserving wastes, strong acid wastes, and printing and photographic wastes.

The frequency distribution of risk estimates for these waste streams is summarized in Exhibit 5-27. As illustrated, risks range from 10^{-2} to 10^{-8}, with the highest risks exhibited by pesticide wastes (particularly aldicarb, which is much more mobile than the other selected pesticide, lindane) and wood preserving wastewaters, which contain relatively immobile but very toxic constituents. Low-risk waste streams include K086, waste ink sludges and solvents, and strong acid/alkali wastes.

One caution that should be observed in evaluating the results of the waste stream comparison is our lack of data on waste stream characteristics for waste streams D001, D002, and D003 (unspecified ignitable, corrosive, and reactive wastes, respectively). As outlined in Chapter 4, we determined the characteristics for these wastes using only one data source, which was based on information on incinerated wastes. Because incinerated wastes must generally have a high content of flammable (i.e., organic) constituents, the wastes used in the analysis may have artificially high concentrations of some of the constituents that are driving risk (e.g., methanol, xylene, acetone, etc.). The use of these characteristics for D wastes in our analysis probably over-estimates risks for these waste streams.

EXHIBIT 5-26

COMPARISON OF RISKS FOR WASTE STREAMS ABOVE-GROUND, ON GRADE, CARBON STEEL STORAGE TANK (210,000 GAL) FLOW FIELD C, ALL WASTE STREAMS

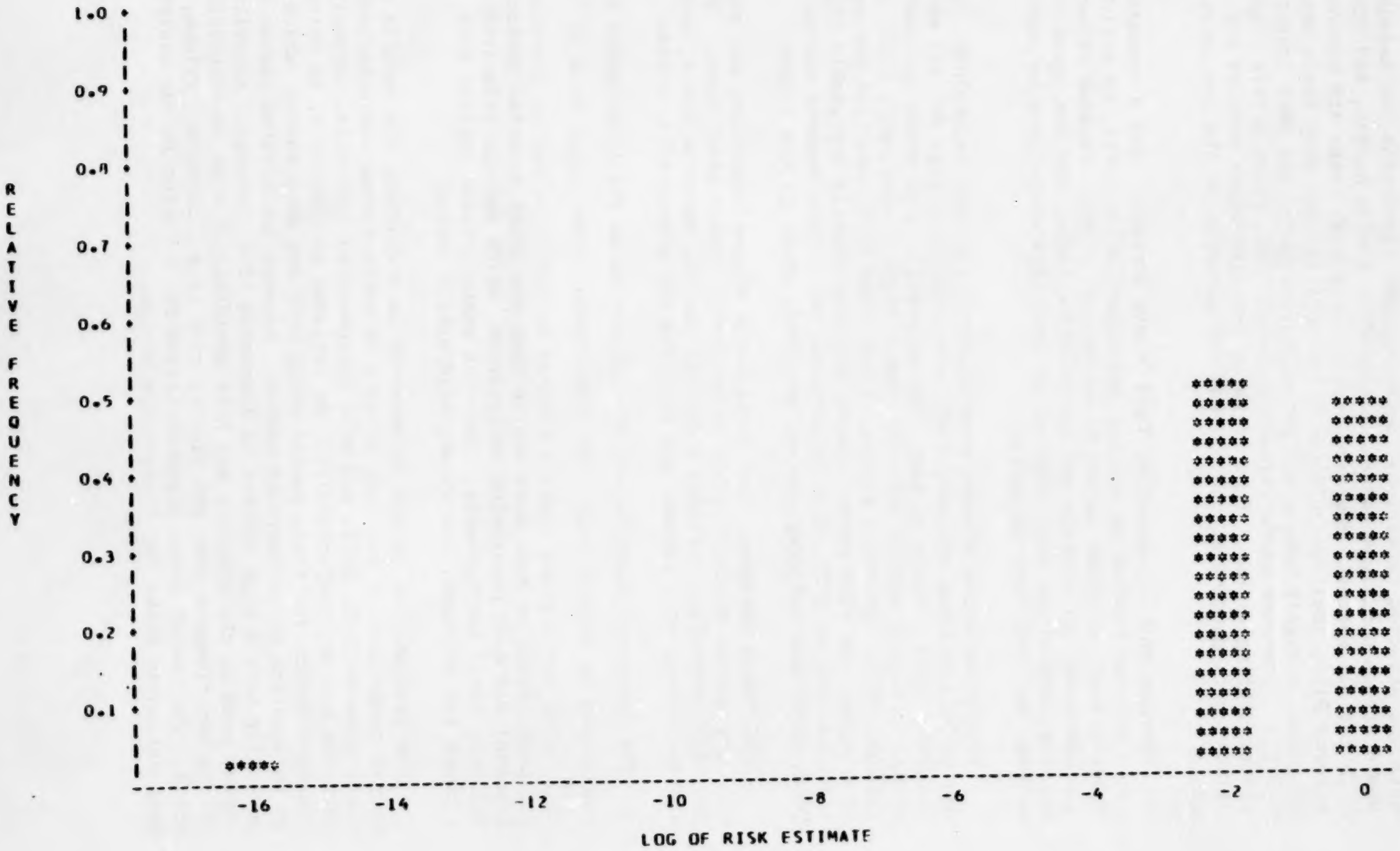
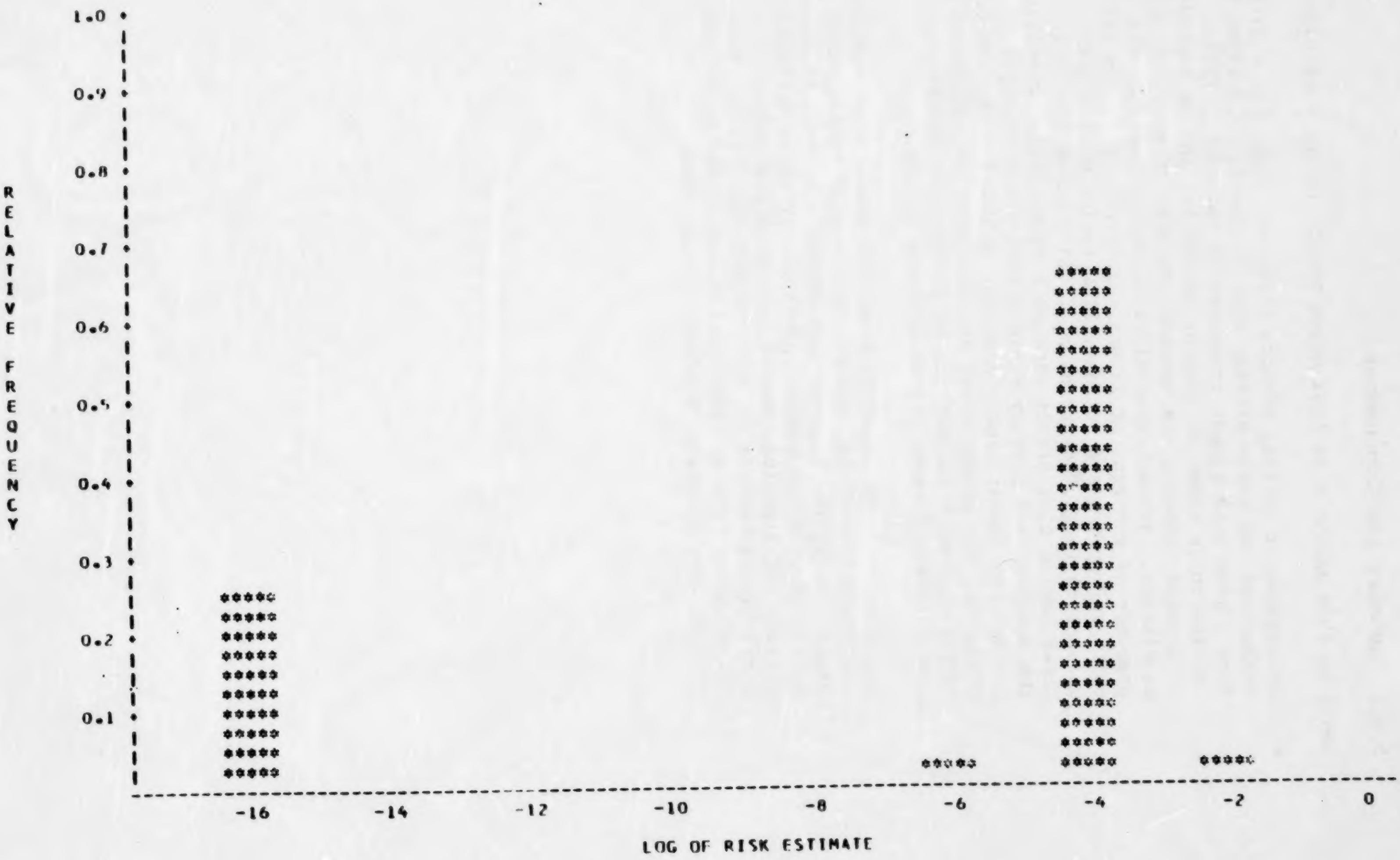


EXHIBIT 5-27

COMPARISON OF RISK FOR WASTE STREAMS
UNDERGROUND, CARBON STEEL SQG TANK (200 gal.)
FLOW FIELD C, ALL WASTE STREAMS



5.4.3 Summary and Conclusions

Based on this analysis we have drawn the following conclusions:

- Hydrogeologic setting affects risk such that, for a given technology and waste stream, risk is generally greater for flow fields with slower ground-water velocity. This conclusion is somewhat counter-intuitive, and is dependent on complex interactions between contaminant mobility and persistence, ground-water dilution and dispersion, and the presence of non-aquifer layers. However, it can be said that, for most waste streams, flow fields with higher velocities (e.g., scenarios B, C, I) present the lower risks, while flow fields such as F (non-aquifer overlying the aquifer) and E (very rapid ground-water velocity), present the lowest risk. However, in developing risk-based standards, the ground-water scenario must be considered in conjunction with information on potentially exposed populations and waste stream characteristics.

- Many waste streams found in hazardous waste tanks present relatively high risks, due to their highly concentrated nature. Among the highest-risk wastes are spent solvents, certain heavy metal wastes (particularly those containing thallium and arsenic), phenol, and reactive wastes (acrylonitile/cyanide, 2,4-dinitrotoluene, etc.). More dilute wastes such as spent pickle liquor and petroleum refining wastes generally present lower risks.

APPENDIX A

FAILURE FREQUENCY DATA AND REPRESENTATIVE RELEASE PROFILES

This appendix contains the summary output from the Hazardous Waste Tank Failure (HWTF) Model. The appendix consists of six exhibits. Exhibit A-1 through A-3 present the failure frequency data for treatment tanks, storage/accumulation tanks, and SQG tanks, respectively. Exhibits A-4 through A-6 present the representative release profiles for the three tank categories. An explanation of the data presented in the exhibits is provided in Section 5.2.1 of the report.

With the exception of the risk estimates for the partial secondary containment with groundwater monitoring regulatory scenario, the risk estimates presented in Section 5.3 of the report are based on the representative release profiles in Exhibits A-4, A-5, and A-6. In the case of the two regulatory scenarios with ground water monitoring, the representative release profiles used to generate the risk estimates are modified versions of those presented in Exhibits A-4, A-5, and A-6. The modification entailed setting release volumes to zero once releases were detected via groundwater monitoring and abated. This modification was necessary because groundwater monitoring was not incorporated in the HWTF model.

EXHIBIT A-1

FAILURE FREQUENCIES FOR TREATMENT TANKS

Treatment Tank Technology 1
Above-ground, on cradles, carbon steel, closed, 2,300 gallons
Baseline, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	70.6	0.4	0.0	0.0	8.2	0.4	1.3	1.3	0.4	0.4
2- 5	0.0	0.0	29.4	0.4	0.0	0.0	52.4	4.3	2.2	14.8	3.5	0.0
6-10	0.0	0.0	0.0	1.3	0.0	0.0	13.9	6.1	6.9	28.1	16.5	1.3
11-15	0.0	0.0	0.0	0.4	0.4	0.4	5.6	5.2	5.3	26.4	16.9	2.2
16-20	0.0	0.0	0.0	0.0	0.0	0.4	2.6	4.7	3.9	21.2	20.8	0.4
TOTAL	0.0	0.0	100.0	2.5	0.4	0.8	82.7	20.7	19.6	91.8	58.1	4.3

Treatment Tank Technology 1
Above-ground, on cradles, carbon steel, closed, 2,300 gallons
Secondary Containment, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	75.6	1.2	0.8	1.2	0.0	1.2	0.8	0.8	0.0	0.0
2- 5	0.0	0.0	24.4	0.0	0.0	0.0	40.4	3.6	4.4	5.2	1.2	0.4
6-10	0.0	0.0	0.0	0.8	0.0	0.0	29.2	4.4	4.4	18.0	9.6	2.0
11-15	0.0	0.0	0.0	0.4	0.0	0.4	11.2	4.4	5.6	27.6	15.6	1.6
16-20	0.0	0.0	0.0	0.0	0.0	0.4	3.2	4.8	2.0	29.6	21.6	1.2
TOTAL	0.0	0.0	100.0	2.4	0.8	2.0	84.0	18.4	17.2	81.2	48.0	5.2

Treatment Tank Technology 2
Above-ground, on cradles, carbon steel, open, 2,300 gallons
Baseline, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	9.5	0.0	0.0	0.0	10.9	2.3	1.4	1.4	0.5	0.0
2- 5	0.0	0.0	19.4	1.9	0.0	0.0	64.7	3.3	4.6	10.0	10.8	0.0
6-10	0.0	0.0	25.3	1.0	0.0	0.0	7.8	8.7	5.0	15.8	17.1	1.5
11-15	0.0	0.0	15.9	0.5	1.0	1.0	5.2	7.3	6.8	10.1	15.0	1.4
16-20	0.0	0.0	6.5	0.9	0.0	0.5	1.9	5.0	6.0	1.4	24.0	2.4
TOTAL	0.0	0.0	76.6	4.3	1.0	1.5	90.5	26.6	23.8	38.7	67.4	5.3

EXHIBIT A-1 (continued)

FAILURE FREQUENCIES FOR TREATMENT TANKS

Treatment Tank Technology 2
Above-ground, on cradles, carbon steel, open, 2,300 gallons
Secondary Containment, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	5.6	0.4	1.2	2.0	0.0	2.0	0.8	2.0	0.4	0.0
2- 5	0.0	0.0	25.6	0.0	0.0	0.0	45.2	4.4	4.0	5.2	1.2	0.4
6-10	0.0	0.0	21.2	0.4	0.0	0.0	27.2	8.4	6.8	14.0	10.4	2.0
11-15	0.0	0.0	15.2	2.0	0.4	0.0	6.8	4.4	9.6	16.4	16.8	1.6
16-20	0.0	0.0	8.8	2.0	0.0	0.0	6.4	6.0	3.2	7.2	17.6	1.2
TOTAL	0.0	0.0	76.4	4.8	1.6	2.0	85.6	25.2	24.4	44.8	46.4	5.2

Treatment Tank Technology 4
Above-ground, ongrade, carbon steel, 60,000 gallons
Baseline, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	7.8	0.0	0.0	3.3	35.2	1.2	11.1	1.2	9.8	0.0
2- 5	0.0	0.0	20.4	2.0	0.0	0.0	40.2	5.7	4.1	13.2	10.2	1.6
6-10	0.0	0.0	22.6	0.0	0.8	0.0	11.3	6.5	7.3	15.7	8.5	0.4
11-15	0.0	0.0	14.8	0.4	0.0	0.0	4.0	5.2	4.8	1.6	10.2	1.6
16-20	0.0	0.0	7.6	1.6	0.0	0.0	3.2	5.6	3.6	2.8	9.8	2.8
TOTAL	0.0	0.0	73.2	4.0	0.8	3.3	93.9	24.2	30.9	34.5	48.5	6.4

Treatment Tank Technology 4
Above-ground, ongrade, carbon steel, 60,000 gallons
Corrosion Protection, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	7.8	0.8	0.0	3.3	34.0	1.2	16.0	0.0	8.2	0.0
2- 5	0.0	0.0	20.4	0.8	0.0	0.0	41.8	5.7	5.7	0.0	0.4	1.6
6-10	0.0	0.0	22.6	0.4	0.0	0.0	9.7	6.5	3.2	2.8	0.0	0.4
11-15	0.0	0.0	14.8	1.6	0.0	0.0	4.8	5.2	5.2	1.6	0.0	1.6
16-20	0.0	0.0	7.6	0.4	0.0	0.0	2.4	5.6	3.2	3.2	0.8	2.8
TOTAL	0.0	0.0	73.2	4.0	0.0	3.3	92.7	24.2	33.3	7.6	9.4	6.4

EXHIBIT A-1 (continued)

FAILURE FREQUENCIES FOR TREATMENT TANKS

Treatment Tank Technology 4
Above-ground, ongrade, carbon steel, 60,000 gallons
Partial Containment with Ground-water Monitoring, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	7.8	0.0	0.0	3.3	26.6	1.2	15.6	4.5	10.2	0.0
2- 5	0.0	0.0	20.4	0.8	0.4	0.0	45.2	5.7	6.9	13.9	6.2	1.6
6-10	0.0	0.0	22.6	1.2	0.0	0.0	12.7	6.5	4.4	15.4	8.6	0.4
11-15	0.0	0.0	14.8	0.8	0.0	0.0	4.8	5.2	4.0	3.6	4.8	1.6
16-20	0.0	0.0	7.6	1.2	0.0	0.0	2.4	5.6	4.0	3.6	13.5	2.8
TOTAL	0.0	0.0	73.2	4.0	0.4	3.3	91.7	24.2	34.9	41.0	43.3	6.4

Treatment Tank Technology 4
Above-ground, ongrade, carbon steel, 60,000 gallons
Secondary Containment, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	5.6	0.4	1.2	2.0	0.0	2.0	0.8	2.0	0.4	0.0
2- 5	0.0	0.0	25.6	0.0	0.0	0.0	45.2	4.4	4.0	5.2	1.2	0.4
6-10	0.0	0.0	21.2	0.4	0.0	0.0	26.8	8.4	6.8	14.0	7.6	2.0
11-15	0.0	0.0	15.2	2.0	0.4	0.4	7.6	4.4	8.8	16.4	10.0	1.6
16-20	0.0	0.0	8.8	0.8	0.0	0.0	6.0	6.0	4.0	7.2	5.2	1.2
TOTAL	0.0	0.0	76.4	3.6	1.6	2.4	85.6	25.2	24.4	44.8	24.4	5.2

Treatment Tank Technology 5
In-ground, concrete, 3,700 gallons
Baseline, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	7.0	0.0	0.0	2.1	28.8	2.9	0.0	3.7	0.0	0.4
2- 5	0.0	0.0	25.9	0.4	0.0	0.0	46.9	6.9	0.0	18.5	0.0	1.2
6-10	0.0	0.0	22.6	0.0	0.0	0.0	10.3	3.2	0.8	13.9	0.0	1.2
11-15	0.0	0.0	15.3	1.6	0.0	0.0	4.0	4.0	12.7	2.8	0.0	1.6
16-20	0.0	0.0	6.1	0.8	0.0	0.0	4.4	4.4	25.6	5.2	0.0	1.2
TOTAL	0.0	0.0	76.9	2.8	0.0	2.1	94.4	21.4	39.1	44.1	0.0	5.6

EXHIBIT A-1 (continued)

FAILURE FREQUENCIES FOR TREATMENT TANKS

Treatment Tank Technology 5
In-ground, concrete, 3,700 gallons
Partial Containment with Ground-water Monitoring, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	7.0	0.4	0.0	2.1	34.2	2.9	0.0	4.9	0.0	0.4
2- 5	0.0	0.0	25.9	0.8	0.0	0.0	42.0	6.9	0.0	17.3	0.0	1.2
6-10	0.0	0.0	22.6	0.4	0.0	0.0	11.8	3.2	2.4	11.0	0.0	1.2
11-15	0.0	0.0	15.3	0.4	0.0	0.0	4.0	4.0	10.6	2.8	0.0	1.6
16-20	0.0	0.0	6.1	1.2	0.4	0.0	0.8	4.4	29.6	2.8	0.0	1.2
TOTAL	0.0	0.0	76.9	3.2	0.4	2.1	92.8	21.4	42.6	38.8	0.0	5.6

Treatment Tank Technology 5
In-ground, concrete, 3,700 gallons
Secondary Containment, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	5.6	1.2	0.8	0.4	0.0	2.0	0.0	2.8	0.0	0.0
2- 5	0.0	0.0	25.6	1.6	0.0	0.0	44.4	4.4	0.0	7.6	0.0	0.4
6-10	0.0	0.0	21.2	0.0	0.0	0.0	31.2	8.4	0.0	12.8	0.0	2.0
11-15	0.0	0.0	15.2	1.6	0.0	0.0	7.6	4.4	0.8	17.6	0.0	1.6
16-20	0.0	0.0	8.8	0.8	0.0	0.0	4.8	6.0	3.2	4.0	0.0	1.2
TOTAL	0.0	0.0	76.4	5.2	0.8	0.4	88.0	25.2	4.0	44.8	0.0	5.2

Treatment Tank Technology 6
In-ground, carbon steel, 3,700 gallons
Baseline, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	7.1	0.0	0.0	0.8	32.4	2.9	17.8	0.4	53.1	0.4
2- 5	0.0	0.0	26.1	1.2	0.0	0.0	41.9	7.1	3.7	18.4	17.0	1.2
6-10	0.0	0.0	21.9	1.2	0.0	0.0	10.3	3.2	6.6	13.7	15.3	1.2
11-15	0.0	0.0	15.3	1.6	0.0	0.0	5.8	4.1	4.0	1.2	9.2	1.6
16-20	0.0	0.0	6.3	0.4	0.0	0.0	2.8	4.1	4.1	2.0	3.3	1.2
TOTAL	0.0	0.0	76.7	4.4	0.0	0.8	93.2	21.4	36.2	35.7	97.9	5.6

EXHIBIT A-1 (continued)

FAILURE FREQUENCIES FOR TREATMENT TANKS

Treatment Tank Technology 6
In-ground, carbon steel, 3,700 gallons
Corrosion Protection, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	7.1	0.0	0.0	0.8	33.6	2.9	13.3	0.4	49.8	0.4
2- 5	0.0	0.0	26.1	1.6	0.0	0.0	44.4	7.1	5.0	0.0	2.0	1.2
6-10	0.0	0.0	21.9	0.8	0.0	0.0	8.7	3.2	5.8	0.0	1.6	1.2
11-15	0.0	0.0	15.3	0.8	0.0	0.0	2.8	4.1	6.2	2.4	2.8	1.6
16-20	0.0	0.0	6.3	0.0	0.0	0.0	2.8	4.1	3.6	2.0	2.8	1.2
TOTAL	0.0	0.0	76.7	3.2	0.0	0.8	92.3	21.4	33.9	4.8	59.0	5.6

Treatment Tank Technology 6
In-ground, carbon steel, 3,700 gallons
Partial Containment with Ground-water Monitoring, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	6.7	0.0	0.0	0.8	36.4	2.9	13.8	2.5	47.3	0.4
2- 5	0.0	0.0	25.9	0.8	0.4	0.0	38.5	7.2	2.9	18.0	24.7	1.2
6-10	0.0	0.0	22.2	0.4	0.0	0.0	9.6	3.3	7.6	12.2	18.4	1.2
11-15	0.0	0.0	15.5	0.8	0.0	0.0	5.4	4.1	4.7	2.4	6.3	1.6
16-20	0.0	0.0	6.3	0.4	0.0	0.0	2.9	4.2	7.1	3.7	2.8	1.2
TOTAL	0.0	0.0	76.6	2.4	0.4	0.8	92.8	21.7	36.1	38.8	99.5	5.6

Treatment Tank Technology 6
In-ground, carbon steel, 3,700 gallons
Secondary Containment, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	5.6	0.4	1.2	11.2	0.0	2.0	2.4	2.0	0.0	0.0
2- 5	0.0	0.0	25.6	0.0	0.0	0.0	45.2	4.4	7.2	8.4	8.4	0.4
6-10	0.0	0.0	21.2	0.4	0.0	0.0	27.2	8.4	11.6	12.4	29.2	2.0
11-15	0.0	0.0	15.2	2.4	0.4	0.0	7.2	4.4	5.6	19.2	14.8	1.6
16-20	0.0	0.0	8.8	0.8	0.0	0.0	7.6	6.0	9.2	7.2	14.8	1.2
TOTAL	0.0	0.0	76.4	4.0	1.6	11.2	87.2	25.2	36.0	49.2	67.2	5.2

EXHIBIT A-1 (continued)

FAILURE FREQUENCIES FOR TREATMENT TANKS

Treatment Tank Technology 7
In-ground, stainless steel, 3,700 gallons
Baseline, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	7.0	0.0	0.0	0.8	33.9	2.9	16.1	2.5	2.5	0.4
2- 5	0.0	0.0	26.1	0.4	0.0	0.0	42.1	7.1	4.6	6.1	4.6	1.2
6-10	0.0	0.0	22.2	0.0	0.0	0.0	10.4	3.2	5.8	7.5	7.0	1.2
11-15	0.0	0.0	15.3	1.2	0.0	0.0	5.3	4.1	3.2	4.9	10.3	1.6
16-20	0.0	0.0	6.3	0.4	0.0	0.0	2.9	4.1	3.6	7.1	13.6	1.2
TOTAL	0.0	0.0	76.9	2.0	0.0	0.8	94.6	21.4	33.3	28.1	38.0	5.6

Treatment Tank Technology 7
In-ground, stainless steel, 3,700 gallons
Corrosion Protection, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	7.0	0.0	0.0	0.8	31.0	2.9	14.5	0.0	1.2	0.4
2- 5	0.0	0.0	26.1	1.2	0.0	0.0	45.9	7.1	4.5	0.8	0.0	1.2
6-10	0.0	0.0	22.2	0.4	0.0	0.0	12.4	3.2	8.7	1.6	0.0	1.2
11-15	0.0	0.0	15.3	0.4	0.0	0.0	2.8	4.1	5.4	1.2	0.4	1.6
16-20	0.0	0.0	6.3	0.4	0.0	0.0	1.2	4.1	5.3	1.2	0.4	1.2
TOTAL	0.0	0.0	76.9	2.4	0.0	0.8	93.3	21.4	38.4	4.8	2.0	5.6

Treatment Tank Technology 7
In-ground, stainless steel, 3,700 gallons
Partial Containment with Ground-water Monitoring, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	7.0	0.4	0.0	0.8	38.0	2.9	13.2	0.8	2.9	0.4
2- 5	0.0	0.0	26.1	1.2	0.0	0.0	37.1	7.1	5.4	4.1	2.0	1.2
6-10	0.0	0.0	22.2	0.4	0.0	0.0	11.2	3.2	6.2	4.0	9.5	1.2
11-15	0.0	0.0	15.3	0.8	0.0	0.0	2.4	4.1	5.2	6.2	11.6	1.6
16-20	0.0	0.0	6.3	0.0	0.0	0.0	3.7	4.1	7.4	3.6	9.1	1.2
TOTAL	0.0	0.0	76.9	2.8	0.0	0.8	92.4	21.4	37.4	18.7	35.1	5.6

EXHIBIT A-1 (continued)

FAILURE FREQUENCIES FOR TREATMENT TANKS

Treatment Tank Technology 7
In-ground, stainless steel, 3,700 gallons
Secondary Containment, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	0.0	0.0	5.6	0.4	1.2	11.2	0.0	2.0	2.0	2.0	0.4	0.0
2- 5	0.0	0.0	25.6	1.2	0.0	0.0	48.4	4.4	9.2	2.8	0.4	0.4
6-10	0.0	0.0	21.2	0.8	0.0	0.4	24.4	8.4	12.0	4.4	0.0	2.0
11-15	0.0	0.0	15.2	1.6	0.0	0.0	9.2	4.4	8.8	4.8	1.6	1.6
16-20	0.0	0.0	8.8	1.6	0.4	0.0	6.0	6.0	6.0	3.2	3.6	1.2
TOTAL	0.0	0.0	76.4	5.6	1.6	11.6	88.0	25.2	38.0	17.2	6.0	5.2

EXHIBIT A-2

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 8 and Accumulation Tank Technology 17
Above-ground, on cradles, carbon steel, 5,500 gallons
Baseline, Aqueous and Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	2.1	4.6	2.1	0.0	0.0	0.0	16.9	0.0	0.4	0.8	0.0	0.4
2- 5	7.2	13.9	12.6	0.0	0.0	0.0	27.0	2.4	1.2	2.1	9.3	1.2
6-10	6.8	12.7	15.2	0.0	0.0	0.0	14.4	3.2	3.3	2.4	19.4	1.6
11-15	10.1	12.3	9.7	0.4	0.0	0.0	8.1	2.4	1.6	2.9	13.1	0.0
16-20	7.6	9.7	8.9	0.4	0.0	0.0	8.0	2.4	1.2	0.8	14.9	0.8
TOTAL	33.8	53.2	48.5	0.8	0.0	0.0	74.4	10.4	7.7	9.0	56.7	4.0

Storage Tank Technology 8 and Accumulation Tank Technology 17
Above-ground, on cradles, carbon steel, 5,500 gallons
Secondary Containment, Aqueous and Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	1.6	2.8	2.0	0.8	0.8	0.8	0.0	0.8	0.8	0.8	0.0	0.0
2- 5	7.6	17.2	8.4	0.0	0.0	0.0	20.8	2.0	1.2	1.2	0.4	0.4
6-10	9.2	15.2	8.8	0.0	0.0	0.4	26.8	2.4	1.6	4.4	6.4	2.0
11-15	9.2	11.6	8.4	1.2	0.0	0.0	17.2	1.6	2.4	6.0	14.4	1.6
16-20	8.0	6.8	5.6	0.4	0.0	0.0	8.0	2.8	2.8	1.6	16.0	1.2
TOTAL	35.6	53.6	33.2	2.4	0.8	1.2	72.8	9.6	8.8	14.0	37.2	5.2

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Baseline, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	0.4	0.0	0.0	0.4	17.8	1.3	4.9	9.8	16.9	0.4
2- 5	0.0	0.0	0.0	0.8	0.4	0.4	33.3	3.9	1.2	35.0	7.6	0.8
6-10	0.0	0.0	0.8	0.0	0.0	0.0	17.3	0.4	0.8	28.8	10.6	2.6
11-15	0.0	0.0	0.8	0.4	0.8	0.0	7.9	4.4	2.6	14.7	9.3	1.8
16-20	0.0	0.0	0.0	0.0	0.0	0.0	4.9	3.1	2.2	10.2	6.6	0.4
TOTAL	0.0	0.0	2.0	1.2	1.2	0.8	81.2	13.1	11.7	98.5	51.0	6.0

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Baseline, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	0.4	0.0	0.0	0.4	17.5	1.3	6.1	9.6	17.1	0.4
2- 5	0.0	0.0	0.0	0.8	0.4	0.4	33.8	3.9	1.2	35.0	7.5	0.8
6-10	0.0	0.0	0.8	0.0	0.0	0.0	17.1	0.8	0.8	28.9	10.5	2.6
11-15	0.0	0.0	0.8	0.4	0.8	0.0	7.8	4.4	2.6	14.4	8.7	1.8
16-20	0.0	0.0	0.0	0.0	0.0	0.0	5.4	3.5	2.2	10.4	6.9	0.8
TOTAL	0.0	0.0	2.0	1.2	1.2	0.8	81.6	13.9	12.9	98.3	50.7	6.4

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Corrosion Protection, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	0.4	0.0	0.0	0.4	18.2	1.3	5.3	0.0	14.7	0.4
2- 5	0.0	0.0	0.0	1.2	0.0	0.4	37.4	3.9	1.7	2.6	1.2	0.8
6-10	0.0	0.0	0.8	0.0	0.0	0.0	15.6	0.4	0.8	12.4	1.7	2.6
11-15	0.0	0.0	0.8	0.4	0.0	0.0	8.0	4.4	1.2	14.6	0.4	1.8
16-20	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.1	2.2	11.2	1.3	0.4
TOTAL	0.0	0.0	2.0	1.6	0.0	0.8	82.3	13.1	11.2	40.8	19.3	6.0

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Corrosion Protection, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	0.4	0.0	0.0	0.4	18.0	1.3	6.6	0.0	14.9	0.4
2- 5	0.0	0.0	0.0	1.2	0.0	0.4	37.8	3.9	1.7	2.6	1.2	0.8
6-10	0.0	0.0	0.8	0.0	0.0	0.0	15.3	0.8	0.8	12.2	1.7	2.6
11-15	0.0	0.0	0.8	0.4	0.0	0.0	7.9	4.4	1.2	14.4	0.4	1.8
16-20	0.0	0.0	0.0	0.0	0.0	0.0	3.5	3.5	2.2	11.0	1.3	0.8
TOTAL	0.0	0.0	2.0	1.6	0.0	0.8	82.5	13.9	12.5	40.2	19.5	6.4

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Partial Containment with Ground-water Monitoring, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	0.0	0.4	0.0	0.9	16.4	1.3	4.4	0.4	17.3	0.4
2- 5	0.0	0.0	0.0	1.6	0.0	0.4	36.9	3.9	2.6	1.7	6.2	1.2
6-10	0.0	0.0	0.0	0.4	0.0	0.0	21.4	0.8	2.1	4.8	11.1	2.6
11-15	0.0	0.0	0.0	0.0	0.0	0.0	4.7	4.4	1.7	2.6	9.4	1.8
16-20	0.0	0.0	0.0	0.4	0.0	0.0	4.9	3.1	2.9	1.7	13.8	0.4
TOTAL	0.0	0.0	0.0	2.8	0.0	1.3	84.3	13.5	13.7	11.2	57.8	6.4

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Partial Containment with Ground-water Monitoring, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	0.0	0.4	0.0	1.3	17.1	1.3	5.3	1.3	17.1	0.4
2- 5	0.0	0.0	0.0	1.6	0.0	0.4	36.9	3.9	2.6	1.7	6.6	1.2
6-10	0.0	0.0	0.0	0.4	0.0	0.0	21.1	0.8	2.1	4.8	11.0	2.6
11-15	0.0	0.0	0.0	0.0	0.0	0.0	4.7	4.4	1.7	2.6	9.1	1.8
16-20	0.0	0.0	0.0	0.4	0.0	0.0	4.9	3.5	2.9	1.7	13.6	0.8
TOTAL	0.0	0.0	0.0	2.8	0.0	1.7	84.7	13.9	14.6	12.1	57.4	6.8

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Secondary Containment, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.0	0.0	0.8	0.8	0.8	0.0	0.8	0.8	0.8	0.0	0.0
2- 5	0.0	0.0	1.2	0.0	0.0	0.0	24.4	2.0	1.6	2.8	0.4	0.4
6-10	0.0	0.0	0.0	0.8	0.0	0.0	22.0	2.4	2.8	11.6	2.8	2.0
11-15	0.0	0.0	0.4	0.4	0.0	0.0	16.0	1.6	2.8	18.0	6.0	1.6
16-20	0.0	0.0	0.8	0.0	0.0	0.0	6.0	2.8	2.8	30.0	5.6	1.2
TOTAL	0.0	0.0	2.4	2.0	0.8	0.8	68.4	9.6	10.8	63.2	14.8	5.2

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Baseline, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	0.0	4.2	0.0	0.4	0.8	0.0	22.3	4.6	0.0	5.5	16.8	0.0
2- 5	6.4	14.3	1.2	0.0	0.0	0.0	13.8	2.0	2.5	2.5	26.9	0.4
6-10	5.9	16.4	1.3	0.0	0.0	0.0	9.2	1.2	2.5	0.0	24.8	1.3
11-15	6.3	11.3	1.2	0.0	0.0	0.0	9.7	2.8	2.9	3.3	13.4	0.4
16-20	6.3	8.4	1.2	0.0	0.0	0.4	6.0	2.4	4.2	3.7	5.0	0.0
TOTAL	24.9	54.6	4.9	0.4	0.8	0.4	61.0	13.0	12.1	15.0	86.9	2.1

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Baseline, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	0.0	2.9	0.0	0.4	0.8	0.0	16.2	4.6	0.4	4.6	16.7	0.0
2- 5	6.3	12.1	1.2	0.0	0.0	0.0	13.3	1.6	3.2	2.0	27.5	0.4
6-10	6.2	18.3	1.2	0.0	0.0	0.0	13.7	2.0	1.2	1.6	24.6	1.2
11-15	6.2	7.9	2.4	0.0	0.0	0.4	8.7	2.8	2.8	2.8	11.3	0.4
16-20	6.2	12.1	0.8	0.0	0.0	0.0	9.6	2.4	3.7	3.3	5.8	0.0
TOTAL	24.9	53.3	5.6	0.4	0.8	0.4	61.5	13.4	11.3	14.3	85.9	2.0

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Corrosion Protection, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	0.0	3.0	0.0	0.4	0.8	0.0	16.0	4.6	0.4	3.8	11.8	0.0
2- 5	6.4	14.5	1.2	0.0	0.0	0.4	13.6	1.6	2.9	0.0	1.6	0.4
6-10	6.0	15.5	1.3	0.0	0.0	0.0	14.0	1.6	0.8	0.8	1.6	1.3
11-15	6.3	9.7	2.0	0.0	0.0	0.0	8.5	2.8	2.9	0.0	2.0	0.4
16-20	6.3	10.5	1.2	0.0	0.0	0.0	9.7	2.4	3.7	0.4	4.1	0.0
TOTAL	25.0	53.2	5.7	0.4	0.8	0.4	61.8	13.0	10.7	5.0	21.1	2.1

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Corrosion Protection, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	0.0	2.9	0.0	0.4	0.8	0.0	16.2	4.6	0.4	3.7	12.9	0.0
2- 5	6.3	13.7	1.2	0.0	0.0	0.0	13.3	1.6	3.3	0.0	1.6	0.4
6-10	6.2	15.4	1.2	0.0	0.0	0.0	13.7	2.0	0.8	0.8	1.6	1.2
11-15	6.2	10.3	2.0	0.0	0.0	0.0	9.1	2.8	2.8	0.0	2.0	0.4
16-20	6.2	10.8	1.2	0.0	0.0	0.0	9.6	2.4	3.7	0.4	4.0	0.0
TOTAL	24.9	53.1	5.6	0.4	0.8	0.0	61.9	13.4	11.0	4.9	22.1	2.0

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Secondary Containment, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	1.6	5.6	0.0	0.4	2.0	2.8	0.0	0.0	0.4	0.4	0.4	0.0
2- 5	5.2	15.2	0.8	0.0	0.0	0.0	14.4	1.6	2.0	2.8	4.8	0.4
6-10	6.8	11.6	1.2	0.0	0.0	0.0	16.4	3.6	6.4	1.6	18.4	0.4
11-15	6.4	10.0	1.2	0.0	0.0	0.0	14.4	7.2	2.8	1.6	14.0	0.8
16-20	6.8	11.2	0.0	0.0	0.4	0.0	12.4	7.6	1.6	0.0	14.4	0.4
TOTAL	26.8	53.6	3.2	0.4	2.4	2.8	57.6	20.0	13.2	6.4	52.0	2.0

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Secondary Containment, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	1.6	5.6	0.0	0.4	2.0	2.8	0.0	0.0	0.4	0.4	0.4	0.0
2- 5	5.2	15.2	0.8	0.0	0.0	0.0	14.4	1.6	2.0	2.8	4.8	0.4
6-10	6.8	11.6	1.2	0.0	0.0	0.0	16.4	3.6	6.4	1.6	18.4	0.4
11-15	6.4	10.0	1.2	0.0	0.0	0.0	14.4	7.2	2.8	1.6	14.0	0.8
16-20	6.8	11.2	0.0	0.0	0.4	0.0	12.4	7.6	1.6	0.0	14.4	0.4
TOTAL	26.8	53.6	3.2	0.4	2.4	2.8	57.6	20.0	13.2	6.4	52.0	2.0

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Leak Testing with Ground-water Monitoring, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	4.2	0.0	0.0	0.0	0.0	22.6	4.6	0.0	5.4	16.7	0.0
2- 5	6.4	14.5	1.2	0.0	0.0	0.0	13.0	2.0	2.0	1.6	27.2	0.4
6-10	5.9	15.1	1.3	0.0	0.0	0.4	8.8	1.2	2.0	0.0	25.2	1.3
11-15	6.3	12.6	1.2	0.0	0.0	0.0	9.6	2.8	2.9	3.3	12.8	0.4
16-20	6.3	10.5	1.2	0.0	0.0	0.0	6.4	2.4	3.3	3.3	5.0	0.0
TOTAL	24.9	56.9	4.9	0.0	0.0	0.4	60.4	13.0	10.2	13.6	86.9	2.1

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Leak Testing with Ground-water Monitoring, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	4.1	0.0	0.0	0.0	0.0	22.7	4.5	0.0	5.4	17.8	0.0
2- 5	6.3	14.8	1.2	0.0	0.0	0.0	13.3	2.0	2.4	1.6	26.9	0.4
6-10	6.2	15.7	1.2	0.0	0.0	0.4	8.6	1.2	2.0	0.0	24.8	1.2
11-15	6.2	12.9	1.2	0.0	0.0	0.0	9.4	2.8	2.8	3.3	13.2	0.4
16-20	6.2	9.9	1.2	0.0	0.0	0.0	6.5	2.4	3.3	3.3	4.8	0.0
TOTAL	24.9	57.4	4.8	0.0	0.0	0.4	60.5	12.9	10.5	13.6	87.5	2.0

Storage Tank Technology 11 and Accumulation Tank Technology 20
Underground, fiberglass reinforced plastic, 4,000 gallons
Baseline, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	4.7	0.0	0.4	1.3	0.0	20.3	8.2	0.4	0.0	0.0	0.0
2- 5	6.0	14.6	0.8	0.0	0.0	0.0	15.9	3.5	4.0	0.0	0.0	0.4
6-10	6.0	13.5	1.3	0.0	0.0	0.0	9.5	3.9	3.9	0.0	0.0	1.3
11-15	6.5	11.2	2.7	0.0	0.0	0.0	8.7	5.3	4.3	0.0	0.0	0.4
16-20	6.0	11.6	0.8	0.0	0.0	0.0	4.7	3.4	4.7	0.0	0.0	0.0
TOTAL	24.5	55.6	5.6	0.4	1.3	0.0	59.1	24.3	17.3	0.0	0.0	2.1

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 11 and Accumulation Tank Technology 20
Underground, fiberglass reinforced plastic, 4,000 gallons
Baseline, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	4.7	0.0	0.4	1.3	0.0	20.3	8.2	0.4	0.0	0.0	0.0
2- 5	6.0	14.6	0.8	0.0	0.0	0.0	15.9	3.5	4.0	0.0	0.0	0.4
6-10	6.0	13.5	1.3	0.0	0.0	0.0	9.5	3.9	3.9	0.0	0.0	1.3
11-15	6.5	11.2	2.7	0.0	0.0	0.0	8.7	5.3	4.3	0.0	0.0	0.4
16-20	6.0	11.6	0.8	0.0	0.0	0.0	4.7	3.4	4.7	0.0	0.0	0.0
TOTAL	24.5	55.6	5.6	0.4	1.3	0.0	59.1	24.3	17.3	0.0	0.0	2.1

Storage Tank Technology 11 and Accumulation Tank Technology 20
Underground, fiberglass reinforced plastic, 4,000 gallons
Secondary Containment, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	1.6	5.2	0.0	0.4	4.4	4.0	0.0	0.8	0.4	0.0	0.0	0.0
2- 5	5.6	14.8	0.8	0.4	0.0	0.0	13.6	3.6	4.0	0.0	0.0	0.4
6-10	6.8	15.2	1.2	0.0	0.0	0.0	14.0	9.6	8.8	0.4	0.0	0.4
11-15	6.4	10.0	1.2	0.0	0.0	0.0	14.4	9.6	4.0	0.0	0.0	0.8
16-20	6.4	10.4	0.0	0.4	0.4	0.0	12.8	10.0	2.4	0.0	0.0	0.4
TOTAL	26.8	55.6	3.2	1.2	4.8	4.0	54.8	33.6	19.6	0.4	0.0	2.0

Storage Tank Technology 11 and Accumulation Tank Technology 20
Underground, fiberglass reinforced plastic, 4,000 gallons
Secondary Containment, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	1.6	5.2	0.0	0.4	4.4	4.0	0.0	0.8	0.4	0.0	0.0	0.0
2- 5	5.6	14.8	0.8	0.4	0.0	0.0	13.6	3.6	4.0	0.0	0.0	0.4
6-10	6.8	15.2	1.2	0.0	0.0	0.0	14.0	9.6	8.8	0.4	0.0	0.4
11-15	6.4	10.0	1.2	0.0	0.0	0.0	14.4	9.6	4.0	0.0	0.0	0.8
16-20	6.4	10.4	0.0	0.4	0.4	0.0	12.8	10.0	2.4	0.0	0.0	0.4
TOTAL	26.8	55.6	3.2	1.2	4.8	4.0	54.8	33.6	19.6	0.4	0.0	2.0

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 11 and Accumulation Tank Technology 20
Underground, fiberglass reinforced plastic, 4,000 gallons
Leak Testing with Ground-water Monitoring, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	5.5	0.0	0.0	0.4	0.0	20.0	8.1	0.9	0.0	0.0	0.0
2- 5	6.0	14.4	1.3	0.0	0.0	0.0	14.0	3.9	3.5	0.0	0.0	0.4
6-10	6.0	13.7	1.3	0.0	0.0	0.0	7.7	3.9	5.2	0.0	0.0	1.3
11-15	6.5	11.5	1.2	0.0	0.0	0.0	7.0	5.3	6.0	0.0	0.0	0.4
16-20	6.5	9.8	1.3	0.0	0.0	0.0	6.8	3.9	3.0	0.0	0.0	0.0
TOTAL	25.0	54.9	5.1	0.0	0.4	0.0	55.5	25.1	18.6	0.0	0.0	2.1

Storage Tank Technology 11 and Accumulation Tank Technology 20
Underground, fiberglass reinforced plastic, 4,000 gallons
Leak Testing with Ground-water Monitoring, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	5.5	0.0	0.0	0.4	0.0	20.0	8.1	0.9	0.0	0.0	0.0
2- 5	6.0	14.9	1.3	0.0	0.0	0.0	14.0	3.9	3.5	0.0	0.0	0.4
6-10	6.0	13.2	1.3	0.0	0.0	0.0	7.7	3.9	5.2	0.0	0.0	1.3
11-15	6.5	12.0	1.2	0.0	0.0	0.0	7.0	5.3	6.0	0.0	0.0	0.4
16-20	6.5	9.8	1.3	0.0	0.0	0.0	6.8	3.9	3.5	0.0	0.0	0.0
TOTAL	25.0	55.4	5.1	0.0	0.4	0.0	55.5	25.1	19.1	0.0	0.0	2.1

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Baseline, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	3.3	0.0	0.4	0.8	0.0	19.7	4.6	0.4	1.3	0.4	0.0
2- 5	6.4	13.4	1.2	0.0	0.0	0.0	15.1	1.6	2.0	0.4	0.8	0.4
6-10	6.4	17.5	1.3	0.0	0.0	0.0	12.1	1.6	2.9	1.6	1.2	1.3
11-15	6.3	7.9	2.4	0.0	0.0	0.0	6.7	2.8	4.6	0.4	5.1	0.4
16-20	6.3	10.4	0.8	0.0	0.0	0.0	5.4	2.4	2.5	0.8	4.6	0.0
TOTAL	25.4	52.5	5.7	0.4	0.8	0.0	59.0	13.0	12.4	4.5	12.1	2.1

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Baseline, Aqueous

	FAILURE CATEGORY											
YEAR OF FAILURE	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	3.3	0.0	0.4	0.8	0.0	19.7	4.6	0.4	1.3	0.4	0.0
2- 5	6.4	13.4	1.2	0.0	0.0	0.0	15.1	1.6	2.0	0.4	0.8	0.4
6-10	6.4	17.5	1.3	0.0	0.0	0.0	12.1	1.6	2.9	1.6	1.2	1.3
11-15	6.3	7.9	2.4	0.0	0.0	0.0	6.7	2.8	4.6	0.4	5.1	0.4
16-20	6.3	11.3	0.8	0.0	0.0	0.0	5.4	2.4	2.9	0.8	4.6	0.0
TOTAL	25.4	53.4	5.7	0.4	0.8	0.0	59.0	13.0	12.8	4.5	12.1	2.1

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Corrosion Protection, Toluene

	FAILURE CATEGORY											
YEAR OF FAILURE	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	3.3	0.0	0.4	0.8	0.0	19.7	4.6	0.4	1.3	0.4	0.0
2- 5	6.4	13.8	1.2	0.0	0.0	0.0	15.1	1.6	2.0	0.0	0.0	0.4
6-10	6.4	16.3	1.3	0.0	0.0	0.0	12.1	1.6	2.9	0.0	0.0	1.3
11-15	6.3	8.4	2.0	0.0	0.0	0.0	6.7	2.8	3.3	0.0	0.4	0.4
16-20	6.3	11.8	1.2	0.0	0.0	0.0	5.4	2.4	2.9	0.0	0.0	0.0
TOTAL	25.4	53.6	5.7	0.4	0.8	0.0	59.0	13.0	11.5	1.3	0.8	2.1

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Corrosion Protection, Aqueous

	FAILURE CATEGORY											
YEAR OF FAILURE	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	3.3	0.0	0.4	0.8	0.0	19.7	4.6	0.4	1.3	0.4	0.0
2- 5	6.4	13.8	1.2	0.0	0.0	0.0	15.1	1.6	2.0	0.0	0.0	0.4
6-10	6.4	16.3	1.3	0.0	0.0	0.0	12.1	1.6	2.9	0.0	0.0	1.3
11-15	6.3	8.4	2.0	0.0	0.0	0.0	6.7	2.8	3.3	0.0	0.4	0.4
16-20	6.3	11.8	1.2	0.0	0.0	0.0	5.4	2.4	2.9	0.0	0.0	0.0
TOTAL	25.4	53.6	5.7	0.4	0.8	0.0	59.0	13.0	11.5	1.3	0.8	2.1

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Secondary Containment, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	1.6	5.2	0.0	0.4	2.0	2.8	0.0	0.0	0.4	0.0	0.0	0.0
2- 5	5.2	15.6	0.8	0.0	0.0	0.0	17.2	1.6	3.2	0.8	0.0	0.4
6-10	6.8	10.8	1.2	0.0	0.0	0.0	15.2	3.6	6.8	0.4	1.2	0.4
11-15	6.4	10.8	1.2	0.0	0.0	0.0	12.0	7.2	2.8	0.4	1.6	0.8
16-20	6.8	7.6	0.0	0.0	0.4	0.0	9.6	7.2	2.0	1.2	2.0	0.4
TOTAL	26.8	50.0	3.2	0.4	2.4	2.8	54.0	19.6	15.2	2.8	4.8	2.0

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Secondary Containment, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	1.6	5.2	0.0	0.4	2.0	2.8	0.0	0.0	0.4	0.0	0.0	0.0
2- 5	5.2	15.6	0.8	0.0	0.0	0.0	17.2	1.6	3.2	0.8	0.0	0.4
6-10	6.8	10.8	1.2	0.0	0.0	0.0	15.2	3.6	6.8	0.4	1.2	0.4
11-15	6.4	10.8	1.2	0.0	0.0	0.0	12.0	7.2	2.8	0.4	1.6	0.8
16-20	6.8	7.6	0.0	0.0	0.4	0.0	9.6	7.2	2.0	1.2	2.0	0.4
TOTAL	26.8	50.0	3.2	0.4	2.4	2.8	54.0	19.6	15.2	2.8	4.8	2.0

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Leak Testing with Ground-water Monitoring, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	3.3	0.0	0.0	0.0	0.0	22.7	4.5	0.4	1.2	0.0	0.0
2- 5	6.3	14.0	1.2	0.0	0.0	0.0	10.7	2.0	1.6	0.8	0.0	0.4
6-10	6.2	15.3	1.2	0.0	0.0	0.0	16.6	1.6	1.6	0.8	1.6	1.2
11-15	6.2	15.8	1.2	0.0	0.0	0.0	6.6	2.8	3.2	0.4	5.8	0.4
16-20	6.2	6.7	1.2	0.0	0.0	0.0	5.7	2.4	2.8	0.4	6.9	0.0
TOTAL	24.9	55.1	4.8	0.0	0.0	0.0	62.3	13.3	9.6	3.6	14.3	2.0

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Leak Testing with Ground-water Monitoring, Aqueous

	FAILURE CATEGORY											
YEAR OF FAILURE	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	3.3	0.0	0.0	0.0	0.0	22.7	4.5	0.4	1.2	0.0	0.0
2- 5	6.3	14.0	1.2	0.0	0.0	0.0	10.7	2.0	1.6	0.8	0.0	0.4
6-10	6.2	15.3	1.2	0.0	0.0	0.0	16.6	1.6	1.6	0.8	1.6	1.2
11-15	6.2	16.5	1.2	0.0	0.0	0.0	6.6	2.8	3.2	0.4	5.8	0.4
16-20	6.2	7.1	1.2	0.0	0.0	0.0	6.1	2.4	3.2	0.4	6.9	0.0
TOTAL	24.9	56.2	4.8	0.0	0.0	0.0	62.7	13.3	10.0	3.6	14.3	2.0

Storage Tank Technology 13 and Accumulation Tank Technology 22
In-ground, concrete, 2,100 gallons
Baseline, Toluene

	FAILURE CATEGORY											
YEAR OF FAILURE	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.8	6.6	3.3	0.0	0.0	0.0	15.6	0.0	0.0	0.8	0.0	0.0
2- 5	2.4	18.1	17.2	0.4	0.0	0.0	30.3	3.2	0.0	0.8	0.0	0.8
6-10	2.8	8.5	6.5	0.0	0.0	0.0	20.1	2.0	0.4	2.4	0.0	1.6
11-15	2.4	10.7	9.0	0.4	0.0	0.4	9.9	1.6	1.6	0.8	0.0	1.6
16-20	3.6	9.0	6.8	0.0	0.0	0.0	4.8	3.2	9.0	3.2	0.0	0.8
TOTAL	12.0	52.9	42.8	0.8	0.0	0.4	80.7	10.0	11.0	8.0	0.0	4.8

Storage Tank Technology 13 and Accumulation Tank Technology 22
In-ground, concrete, 2,100 gallons
Baseline, Aqueous

	FAILURE CATEGORY											
YEAR OF FAILURE	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.8	6.6	3.3	0.0	0.0	0.0	15.6	0.0	0.0	0.8	0.0	0.0
2- 5	2.4	18.1	17.2	0.4	0.0	0.0	30.3	3.2	0.0	0.8	0.0	0.8
6-10	2.8	8.5	6.5	0.0	0.0	0.0	20.1	2.0	0.4	2.4	0.0	1.6
11-15	2.4	10.7	9.0	0.4	0.0	0.4	9.9	1.6	1.6	0.8	0.0	1.6
16-20	3.6	9.0	6.8	0.0	0.0	0.0	4.8	3.2	9.0	3.2	0.0	0.8
TOTAL	12.0	52.9	42.8	0.8	0.0	0.4	80.7	10.0	11.0	8.0	0.0	4.8

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 13 and Accumulation Tank Technology 22
In-ground, concrete, 2,100 gallons
Partial Containment with Ground-water Monitoring, Toluene

YEAR OF FAILURE	FAILURE CATEGORY HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	0.0	4.5	5.3	0.0	0.0	0.0	8.1	0.4	0.0	0.0	0.0	0.0
2- 5	3.2	15.0	11.6	0.4	0.0	0.0	40.8	2.0	0.0	4.8	0.0	1.2
6-10	8.0	15.3	11.3	0.0	0.0	0.0	18.9	2.4	0.0	4.8	0.0	2.0
11-15	3.2	14.0	12.0	0.4	0.4	0.0	7.6	3.2	2.4	3.6	0.0	2.8
16-20	4.0	6.8	8.8	0.0	0.0	0.0	4.8	2.0	5.6	3.2	0.0	0.0
TOTAL	18.4	55.6	49.0	0.8	0.4	0.0	80.2	10.0	8.0	16.4	0.0	6.0

Storage Tank Technology 13 and Accumulation Tank Technology 22
In-ground, Concrete, 2,100 gallons
Partial Containment with Ground-water Monitoring, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	0.0	4.5	5.3	0.0	0.0	0.0	8.1	0.4	0.0	0.0	0.0	0.0
2- 5	3.2	15.0	11.6	0.4	0.0	0.0	40.8	2.0	0.0	4.8	0.0	1.2
6-10	8.0	15.3	11.3	0.0	0.0	0.0	18.9	2.4	0.0	4.8	0.0	2.0
11-15	3.2	14.0	12.0	0.4	0.4	0.0	7.6	3.2	2.4	3.6	0.0	2.8
16-20	4.0	6.8	8.8	0.0	0.0	0.0	4.8	2.0	5.6	3.2	0.0	0.0
TOTAL	18.4	55.6	49.0	0.8	0.4	0.0	80.2	10.0	8.0	16.4	0.0	6.0

Storage Tank Technology 13 and Accumulation Tank Technology 22
In-ground, concrete, 2,100 gallons
Secondary Containment, Toluene

YEAR OF FAILURE	FAILURE CATEGORY HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	0.8	4.4	2.0	1.2	0.4	0.8	0.0	0.8	0.0	0.8	0.0	0.0
2- 5	3.2	16.4	8.0	0.4	0.0	0.0	26.0	2.0	0.0	2.4	0.0	0.4
6-10	3.6	16.0	8.8	0.0	0.0	0.0	20.4	2.4	0.0	4.0	0.0	2.0
11-15	3.2	12.8	8.4	0.4	0.0	0.0	16.4	1.6	0.0	2.8	0.0	1.6
16-20	4.0	11.6	5.6	0.0	0.0	0.0	11.2	2.8	0.8	2.4	0.0	1.2
TOTAL	14.8	61.2	32.8	2.0	0.4	0.8	74.0	9.6	0.8	12.4	0.0	5.2

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 13 and Accumulation Tank Technology 22
In-ground, concrete, 2,100 gallons
Secondary Containment, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	0.8	4.4	2.0	1.2	0.4	0.8	0.0	0.8	0.0	0.8	0.0	0.0
2- 5	3.2	16.4	8.0	0.4	0.0	0.0	26.0	2.0	0.0	2.4	0.0	0.4
6-10	3.6	16.0	8.8	0.0	0.0	0.0	20.4	2.4	0.0	4.0	0.0	2.0
11-15	3.2	12.8	8.4	0.4	0.0	0.0	16.4	1.6	0.0	2.8	0.0	1.6
16-20	4.0	11.6	5.6	0.0	0.0	0.0	11.2	2.8	0.8	2.4	0.0	1.2
TOTAL	14.8	61.2	32.8	2.0	0.4	0.8	74.0	9.6	0.8	12.4	0.0	5.2

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Baseline, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	1.0	5.8	2.9	0.0	0.0	0.0	11.5	0.0	0.5	0.5	9.6	0.0
2- 5	2.5	17.4	17.4	0.0	0.0	0.0	36.6	3.0	1.5	3.4	17.2	1.0
6-10	3.0	6.7	6.8	0.0	0.0	1.5	14.4	2.5	1.5	5.8	23.0	1.5
11-15	2.5	11.2	9.1	0.5	0.5	0.5	10.1	1.5	3.9	2.0	18.7	2.0
16-20	3.4	8.2	4.8	0.5	0.0	0.0	6.3	3.5	1.9	0.5	11.4	0.5
TOTAL	12.4	49.3	41.0	1.0	0.5	2.0	78.9	10.5	9.3	12.2	79.9	5.0

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Baseline, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS- STROPH RLS
1	0.9	6.6	2.8	0.0	0.0	0.0	11.3	0.0	0.5	0.5	11.7	0.0
2- 5	2.3	17.9	16.9	0.0	0.0	0.0	37.1	2.8	1.4	3.3	17.0	1.0
6-10	2.9	6.5	6.6	0.0	0.0	0.5	14.6	2.4	1.5	5.5	22.6	1.5
11-15	2.8	10.9	8.8	0.5	0.5	0.5	9.8	1.4	3.2	1.9	18.3	2.0
16-20	3.3	8.0	5.2	0.5	0.0	0.0	6.1	3.3	1.9	0.5	11.2	1.0
TOTAL	12.2	49.9	40.3	1.0	0.5	1.0	78.9	9.9	8.5	11.7	80.8	5.5

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Corrosion Protection, Toluene

	FAILURE CATEGORY											
YEAR OF FAILURE	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	1.0	5.8	2.9	0.0	0.0	0.0	11.5	0.0	0.5	0.0	4.3	0.0
2- 5	2.5	17.4	17.4	0.0	0.0	0.0	36.6	3.0	1.0	0.0	0.5	1.0
6-10	3.0	7.1	6.8	0.0	0.0	0.0	14.8	2.5	1.5	0.5	3.0	1.5
11-15	2.5	10.7	9.1	0.5	0.0	0.5	9.6	1.5	3.9	1.0	3.0	2.0
16-20	3.4	8.7	4.8	0.5	0.0	0.0	6.8	3.5	1.9	0.0	3.5	0.5
TOTAL	12.4	49.7	41.0	1.0	0.0	0.5	79.3	10.5	8.8	1.5	14.3	5.0

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Corrosion Protection, Aqueous

	FAILURE CATEGORY											
YEAR OF FAILURE	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.9	6.6	2.8	0.0	0.0	0.0	11.3	0.0	0.5	0.0	6.6	0.0
2- 5	2.3	17.9	16.9	0.0	0.0	0.0	37.1	2.8	1.0	0.0	0.5	1.0
6-10	2.9	7.0	6.6	0.0	0.0	0.0	15.1	2.4	1.5	0.5	2.8	1.5
11-15	2.8	10.4	8.8	0.5	0.0	0.5	9.3	1.4	3.7	1.0	2.8	2.0
16-20	3.3	8.4	5.2	0.5	0.0	0.0	6.6	3.3	1.9	0.0	3.3	1.0
TOTAL	12.2	50.3	40.3	1.0	0.0	0.5	79.4	9.9	8.6	1.5	16.0	5.5

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Partial Containment with Ground-water Monitoring, Toluene

	FAILURE CATEGORY											
YEAR OF FAILURE	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	4.9	5.8	0.0	0.0	0.0	6.6	0.4	0.4	0.9	11.9	0.0
2- 5	3.0	13.2	11.5	0.0	0.0	0.0	42.4	1.7	4.0	2.7	25.7	1.3
6-10	6.6	13.7	11.9	0.4	0.0	0.4	14.3	2.6	2.2	5.8	22.1	1.7
11-15	3.5	12.0	12.5	0.0	0.0	0.0	5.2	3.5	3.0	1.7	19.0	2.1
16-20	4.5	8.9	8.4	0.0	0.0	0.0	4.8	1.6	2.2	2.1	4.0	0.0
TOTAL	17.6	52.7	50.1	0.4	0.0	0.4	73.3	9.8	11.8	13.2	82.7	5.1

EXHIBIT A-2 (continued)

FAILURE FREQUENCIES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Partial Containment with Ground-water Monitoring, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	4.8	5.7	0.0	0.0	0.0	6.6	0.4	0.4	0.9	13.1	0.0
2- 5	3.0	13.5	11.9	0.0	0.0	0.0	42.3	1.7	3.9	2.7	25.3	1.3
6-10	6.9	14.1	11.8	0.4	0.0	0.0	14.0	2.6	3.5	5.7	21.9	1.7
11-15	3.4	11.7	12.2	0.0	0.0	0.0	5.2	3.5	2.6	1.7	18.8	2.1
16-20	4.3	8.8	8.7	0.0	0.0	0.4	4.8	2.1	2.2	2.6	4.0	0.0
TOTAL	17.6	52.9	50.3	0.4	0.0	0.4	72.9	10.3	12.6	13.6	83.1	5.1

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Secondary Containment, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.8	2.8	3.2	1.2	0.4	4.0	0.0	0.8	0.4	0.0	0.0	0.0
2- 5	3.2	15.6	14.0	0.4	0.0	0.0	20.4	2.0	2.8	1.6	4.0	0.4
6-10	3.6	14.0	12.8	0.0	0.0	0.0	25.6	2.4	3.2	3.2	19.6	2.0
11-15	3.2	14.4	12.0	0.0	0.0	0.0	18.8	1.6	2.8	5.6	10.4	1.6
16-20	4.0	10.0	8.4	0.4	0.0	0.0	8.4	2.8	2.4	3.2	14.8	1.2
TOTAL	14.8	56.8	50.4	2.0	0.4	4.0	73.2	9.6	11.6	13.6	48.8	5.2

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Secondary Containment, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.8	2.8	3.2	1.2	0.4	4.0	0.0	0.8	0.4	0.0	0.0	0.0
2- 5	3.2	15.6	14.0	0.4	0.0	0.0	20.4	2.0	2.8	1.6	4.0	0.4
6-10	3.6	14.0	12.8	0.0	0.0	0.0	25.6	2.4	3.2	3.2	19.6	2.0
11-15	3.2	14.4	12.0	0.0	0.0	0.0	18.8	1.6	2.8	5.6	10.4	1.6
16-20	4.0	10.0	8.4	0.4	0.0	0.0	8.4	2.8	2.4	3.2	14.8	1.2
TOTAL	14.8	56.8	50.4	2.0	0.4	4.0	73.2	9.6	11.6	13.6	48.8	5.2

EXHIBIT A-3

FAILURE FREQUENCIES FOR SQG TANKS

Small Quantity Generator Tank Technology 15
Above-ground, carbon steel, 200 gallons
Baseline, Aqueous and Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	2.1	2.1	0.0	0.0	0.0	16.8	0.0	0.4	0.8	0.0	0.4
2- 5	0.0	8.4	12.6	0.0	0.0	0.0	27.3	2.4	1.2	2.1	5.9	1.2
6-10	0.4	8.9	15.1	0.0	0.0	0.0	14.2	3.2	3.3	2.4	13.9	1.6
11-15	0.0	8.5	9.6	0.4	0.0	0.8	8.0	2.4	1.2	2.9	14.7	0.0
16-20	0.4	6.2	8.9	0.4	0.0	0.0	8.0	2.4	0.8	0.8	9.6	0.8
TOTAL	0.8	34.1	48.3	0.8	0.0	0.8	74.3	10.4	6.9	9.0	44.1	4.0

Small Quantity Generator Tank Technology 15
Above-ground, carbon steel, 200 gallons
Secondary Containment, Aqueous and Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.4	0.0	2.0	0.8	0.8	0.8	0.0	0.8	0.8	0.8	0.0	0.0
2- 5	0.8	8.8	8.4	0.0	0.0	0.0	20.8	2.0	1.6	1.2	0.4	0.4
6-10	0.4	8.4	8.8	0.0	0.0	0.4	26.8	2.4	1.6	4.4	3.2	2.0
11-15	0.4	7.2	8.4	1.2	0.0	0.0	17.2	1.6	2.0	6.0	11.6	1.6
16-20	0.8	4.8	5.6	0.4	0.0	0.0	8.0	2.8	3.2	1.6	12.0	1.2
TOTAL	2.8	29.2	33.2	2.4	0.8	1.2	72.8	9.6	9.2	14.0	27.2	5.2

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Baseline, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.9	0.0	0.4	0.4	0.0	15.2	4.5	0.9	4.9	5.8	0.0
2- 5	0.4	8.0	1.3	0.0	0.0	0.4	13.4	1.7	2.6	1.6	21.5	0.4
6-10	0.4	7.5	0.9	0.0	0.0	0.0	13.8	1.2	2.1	1.7	23.3	1.3
11-15	1.2	4.8	2.7	0.0	0.0	0.0	8.0	3.0	3.5	3.1	18.3	0.4
16-20	0.4	8.5	0.4	0.4	0.0	0.4	9.3	2.5	3.0	3.1	10.1	0.0
TOTAL	2.4	29.7	5.3	0.8	0.4	0.8	59.7	12.9	12.1	14.4	79.0	2.1

EXHIBIT A-3 (continued)

FAILURE FREQUENCIES FOR SQG TANKS

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Baseline, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.9	0.0	0.4	0.4	0.0	15.3	4.8	0.9	4.8	8.7	0.0
2- 5	0.4	7.8	1.3	0.0	0.0	0.4	13.1	1.7	2.6	1.6	21.0	0.4
6-10	0.4	7.7	1.3	0.0	0.0	0.4	13.9	1.2	2.1	1.7	22.3	1.3
11-15	1.2	4.4	2.7	0.0	0.0	0.4	8.2	3.0	3.0	3.1	17.9	0.4
16-20	0.4	8.2	0.4	0.4	0.4	0.4	9.9	2.5	2.6	3.1	10.1	0.0
TOTAL	2.4	29.0	5.7	0.8	0.8	1.6	60.4	13.2	11.2	14.3	80.0	2.1

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Corrosion Protection, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.9	0.0	0.4	0.4	0.0	15.2	4.5	0.9	4.0	1.8	0.0
2- 5	0.4	8.9	1.3	0.0	0.0	0.0	13.4	1.7	2.6	0.0	0.8	0.4
6-10	0.4	7.5	0.9	0.0	0.0	0.0	14.2	1.2	0.9	0.9	0.8	1.3
11-15	1.2	6.6	2.2	0.0	0.0	0.0	8.5	3.0	3.9	0.0	2.6	0.4
16-20	0.4	8.5	0.8	0.0	0.0	0.0	9.2	2.5	3.5	0.4	2.6	0.0
TOTAL	2.4	32.4	5.2	0.4	0.4	0.0	60.5	12.9	11.8	5.3	8.6	2.1

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Corrosion Protection, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	0.9	0.0	0.4	0.4	0.0	15.2	4.8	0.9	3.9	4.8	0.0
2- 5	0.4	8.7	1.3	0.0	0.0	0.0	13.0	1.7	2.6	0.0	0.8	0.4
6-10	0.4	7.4	1.3	0.0	0.0	0.0	14.2	1.2	0.9	0.9	0.8	1.3
11-15	1.2	5.6	2.2	0.0	0.0	0.0	8.6	3.0	3.9	0.0	2.6	0.4
16-20	0.4	8.6	0.8	0.0	0.0	0.0	10.0	2.5	3.5	0.4	2.6	0.0
TOTAL	2.4	31.2	5.6	0.4	0.4	0.0	61.0	13.2	11.8	5.2	11.6	2.1

EXHIBIT A-3 (continued)

FAILURE FREQUENCIES FOR SQG TANKS

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Secondary Containment, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.4	3.2	0.0	0.4	2.0	2.4	0.0	0.0	0.4	0.4	0.4	0.0
2- 5	0.8	7.2	0.8	0.0	0.0	0.0	14.4	1.6	2.4	2.8	3.2	0.4
6-10	0.4	7.6	0.8	0.0	0.0	0.0	16.4	3.6	6.0	1.6	13.6	0.4
11-15	0.4	6.4	1.2	0.0	0.0	0.0	14.4	7.2	2.4	1.6	14.4	0.8
16-20	0.8	6.4	0.0	0.0	0.4	0.0	12.4	7.6	2.0	0.0	10.8	0.4
TOTAL	2.8	30.8	2.8	0.4	2.4	2.4	57.6	20.0	13.2	6.4	42.4	2.0

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Secondary Containment, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.4	3.2	0.0	0.4	2.0	2.4	0.0	0.0	0.4	0.4	0.4	0.0
2- 5	0.8	7.2	0.8	0.0	0.0	0.0	14.4	1.6	2.4	2.8	3.2	0.4
6-10	0.4	7.6	0.8	0.0	0.0	0.0	16.4	3.6	6.0	1.6	13.6	0.4
11-15	0.4	6.4	1.2	0.0	0.0	0.0	14.4	7.2	2.4	1.6	14.4	0.8
16-20	0.8	6.4	0.0	0.0	0.4	0.0	12.4	7.6	2.0	0.0	10.8	0.4
TOTAL	2.8	30.8	2.8	0.4	2.4	2.4	57.6	20.0	13.2	6.4	42.4	2.0

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Leak Testing with Ground-water Monitoring, Toluene

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	1.3	0.0	0.0	0.0	0.0	22.9	4.8	0.4	5.7	6.2	0.0
2- 5	0.4	9.2	1.3	0.0	0.0	0.0	13.7	2.2	2.1	1.3	22.9	0.4
6-10	0.4	9.2	0.9	0.0	0.0	0.0	8.7	1.2	2.5	0.0	22.0	1.3
11-15	1.2	7.9	1.2	0.0	0.0	0.0	9.3	3.0	2.6	3.1	19.4	0.4
16-20	0.4	8.3	1.3	0.0	0.0	0.0	5.7	2.5	3.0	3.5	12.4	0.0
TOTAL	2.4	35.9	4.7	0.0	0.0	0.0	60.3	13.7	10.6	13.6	82.9	2.1

EXHIBIT A-3 (continued)

FAILURE FREQUENCIES FOR SQG TANKS

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Leak Testing with Ground-water Monitoring, Aqueous

YEAR OF FAILURE	FAILURE CATEGORY											
	HOSE RUPTR	LOOSE HOSE	OVER FLOW	WELD GASKET INSTAL	PIPE INSTAL DEFIC	TANK INSTAL DEFIC	WELD/ GASKT FAIL	PIPE RUPTR	TANK RUPTR	PIPE CORR	TANK CORR	CATAS-STROPH RLS
1	0.0	1.3	0.0	0.0	0.0	0.0	22.9	4.8	0.4	5.6	7.8	0.0
2- 5	0.4	10.4	1.3	0.0	0.0	0.0	13.4	2.2	1.7	1.3	22.5	0.4
6-10	0.4	9.0	1.3	0.0	0.0	0.0	8.6	1.2	2.1	0.0	21.7	1.3
11-15	1.2	8.2	1.2	0.0	0.0	0.0	9.6	3.0	2.6	3.1	19.1	0.4
16-20	0.4	8.3	1.3	0.0	0.0	0.0	6.1	2.5	3.0	3.5	12.4	0.0
TOTAL	2.4	37.2	5.1	0.0	0.0	0.0	60.6	13.7	9.8	13.5	83.5	2.1

EXHIBIT A-4

REPRESENTATIVE RELEASE PROFILES FOR TREATMENT TANKS

Treatment Tank Technology 1
Above-ground, on cradles, carbon steel, closed, 2,300 gallons
Baseline, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.403	18.116	26.980	8.956	16.070	70.122
2	.277	10.801	11.352	13.850	19.272	55.275
3	.121	11.660	15.609	7.157	15.536	49.962
4	.100	10.622	25.310	10.436	16.300	62.668
5	.100	7.060	15.911	21.010	16.950	60.931
WEIGHTED AVERAGE	1.001	13.472	20.028	11.456	17.019	61.976

Treatment Tank Technology 1
Above-ground, on cradles, carbon steel, closed, 2,300 gallons
Secondary Containment, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.824	0.000	0.000	0.000	0.000	0.000
2	.152	0.000	0.000	0.000	0.443	0.443
3	.008	0.000	10.400	0.000	0.101	10.501
4	.008	0.000	0.000	10.400	0.000	10.400
5	.004	10.400	0.000	0.000	0.000	10.400
6	.004	0.000	0.000	0.000	10.400	10.400
WEIGHTED AVERAGE	1.000	0.042	0.083	0.083	0.110	0.318

Treatment Tank Technology 2
Above-ground, on cradles, carbon steel, open, 2,300 gallons
Baseline, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.837	0.537	4.183	0.111	0.838	5.669
2	.063	0.467	9.127	0.644	0.288	10.526
3	.041	0.659	2.264	2.239	8.798	13.960
4	.041	1.841	2.240	0.846	8.434	13.361
5	.018	15.277	2.476	2.276	4.135	24.164
WEIGHTED AVERAGE	1.000	0.856	4.305	0.301	1.500	6.963

EXHIBIT A-4 (continued)

REPRESENTATIVE RELEASE PROFILES FOR TREATMENT TANKS

Treatment Tank Technology 2
Above-ground, on cradles, carbon steel, open, 2,300 gallons
Secondary Containment, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.840	0.000	0.000	0.000	0.000	0.000
2	.132	0.000	0.000	0.708	0.000	0.708
3	.008	6.960	0.000	0.000	0.000	6.960
4	.008	0.000	11.100	0.000	0.000	11.100
5	.008	0.000	0.000	11.100	0.000	11.100
6	.004	0.000	0.000	0.000	11.100	11.100
WEIGHTED AVERAGE	1.000	0.056	0.089	0.182	0.044	0.371

Treatment Tank Technology 4
Above-ground, ongrade, carbon steel, 60,000 gallons
Baseline, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.840	16.600	17.350	17.470	16.110	67.530
2	.074	245.000	294.500	285.900	256.100	1081.500
3	.066	0.076	133.630	17.234	0.423	151.363
4	.012	0.162	2.408	292.070	301.704	596.343
5	.008	1123.000	1251.000	1248.000	1113.000	4735.000
WEIGHTED AVERAGE	1.000	41.065	55.223	50.458	45.036	191.782

Treatment Tank Technology 4
Above-ground, ongrade, carbon steel, 60,000 gallons
Corrosion Protection, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.926	24.710	28.230	27.590	24.480	105.010
2	.033	0.189	0.871	0.005	140.690	141.755
3	.029	351.500	387.100	394.400	348.300	1481.299
4	.008	962.815	1527.000	1520.000	1370.000	5379.812
5	.004	102.113	0.896	562.000	1064.000	1729.009
WEIGHTED AVERAGE	1.000	41.192	49.615	51.394	52.628	194.829

EXHIBIT A-4 (continued)

REPRESENTATIVE RELEASE PROFILES FOR TREATMENT TANKS

Treatment Tank Technology 4
Above-ground, ongrade, carbon steel, 60,000 gallons
Partial Containment with Ground-water Monitoring, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.594	0.000	0.006	0.150	0.608	0.764
2	.332	0.000	0.000	0.000	0.000	0.000
3	.053	200.300	236.500	236.500	212.900	886.200
4	.008	0.000	0.000	521.200	954.000	1475.200
5	.008	0.000	0.000	291.000	291.077	582.077
6	.004	1122.000	1235.000	1235.000	1112.000	4704.000
WEIGHTED AVERAGE	0.999	15.104	17.478	24.061	26.053	82.697

Treatment Tank Technology 4
Above-ground, ongrade, carbon steel, 60,000 gallons
Secondary Containment, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.840	0.000	0.000	0.000	0.000	0.000
2	.136	0.000	0.000	3.390	0.000	3.390
3	.008	0.000	291.000	0.000	0.000	291.000
4	.008	0.000	0.000	291.000	0.000	291.000
5	.004	291.000	0.000	0.000	0.000	291.000
6	.004	0.000	0.000	0.000	291.000	291.000
WEIGHTED AVERAGE	1.000	1.164	2.328	2.789	1.164	7.445

Treatment Tank Technology 5
In-ground, concrete, 3,700 gallons
Baseline, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.979	5.810	5.940	6.440	8.803	26.993
2	.008	12.517	1.655	18.237	187.300	219.709
3	.004	150.600	165.600	165.700	149.700	631.600
4	.004	332.200	364.000	364.600	329.000	1389.800
5	.004	92.195	3.014	0.961	1.068	97.238
WEIGHTED AVERAGE	0.999	8.088	7.959	8.576	12.036	36.658

EXHIBIT A-4 (continued)

REPRESENTATIVE RELEASE PROFILES FOR TREATMENT TANKS

Treatment Tank Technology 5
In-ground, concrete, 3,700 gallons
Partial Containment with Ground-water Monitoring, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.979	0.795	0.795	0.795	3.155	5.540
2	.008	150.400	165.500	165.500	149.000	630.400
3	.004	17.420	19.100	273.000	282.200	591.719
4	.004	0.795	0.795	202.472	290.300	494.362
5	.004	330.700	364.000	364.000	328.400	1387.099
WEIGHTED AVERAGE	0.999	3.377	3.638	5.460	7.884	20.360

Treatment Tank Technology 5
In-ground, concrete, 3,700 gallons
Secondary Containment, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.904	0.000	0.000	0.000	0.000	0.000
2	.072	0.000	0.092	0.000	0.000	0.092
3	.008	0.000	17.900	0.000	0.000	17.900
4	.008	0.000	0.000	17.900	0.000	17.900
5	.004	0.000	0.135	63.500	0.000	63.635
6	.004	0.000	0.000	0.000	17.900	17.900
WEIGHTED AVERAGE	1.000	0.000	0.150	0.397	0.072	0.619

Treatment Tank Technology 6
In-ground, carbon steel, 3,700 gallons
Baseline, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.967	10.340	10.340	11.790	10.700	43.170
2	.017	368.900	406.100	406.000	366.000	1546.999
3	.008	796.000	891.000	907.000	804.800	3398.800
4	.004	2.424	210.365	971.000	874.700	2058.489
5	.004	10.450	12.190	314.710	585.100	922.450
WEIGHTED AVERAGE	1.000	22.690	24.921	30.702	28.846	107.158

EXHIBIT A-4 (continued)

REPRESENTATIVE RELEASE PROFILES FOR TREATMENT TANKS

Treatment Tank Technology 6
In-ground, carbon steel, 3,700 gallons
Corrosion Protection, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.983	2.140	6.447	15.080	22.110	45.777
2	.004	817.400	900.000	900.000	812.900	3430.300
3	.004	0.120	624.300	925.000	832.600	2382.020
4	.004	585.700	645.000	652.000	583.500	2466.200
5	.004	368.800	406.000	406.000	365.400	1546.199
WEIGHTED AVERAGE	0.999	9.192	16.639	26.356	32.112	84.298

Treatment Tank Technology 6
In-ground, carbon steel, 3,700 gallons
Partial Containment with Ground-water Monitoring, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.954	0.000	0.036	0.498	1.172	1.706
2	.029	166.300	183.000	183.000	164.700	697.000
3	.004	0.000	0.000	0.000	0.000	0.000
4	.004	368.800	406.000	406.000	365.400	1546.199
5	.004	813.000	895.000	895.000	808.500	3411.500
6	.004	545.100	600.000	600.000	540.200	2285.300
WEIGHTED AVERAGE	0.999	11.730	12.945	13.386	12.751	50.812

Treatment Tank Technology 6
In-ground, carbon steel, 3,700 gallons
Secondary Containment, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.844	0.000	0.000	0.311	0.009	0.320
2	.136	0.000	0.000	0.000	0.000	0.000
3	.008	17.900	0.614	0.000	0.307	18.821
4	.004	0.000	23.100	0.010	0.000	23.110
5	.004	0.000	0.000	70.100	0.004	70.104
6	.004	0.000	0.188	44.520	0.170	44.878
WEIGHTED AVERAGE	1.000	0.143	0.098	0.721	0.011	0.973

EXHIBIT A-4 (continued)

REPRESENTATIVE RELEASE PROFILES FOR TREATMENT TANKS

Treatment Tank Technology 7
In-ground, stainless steel, 3,700 gallons
Baseline, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.942	6.800	6.160	6.580	5.203	24.743
2	.041	136.900	150.600	150.000	140.000	577.500
3	.008	369.300	406.900	406.600	365.500	1548.299
4	.004	545.100	600.000	607.000	543.100	2295.200
5	.004	816.000	895.000	897.000	806.600	3414.600
WEIGHTED AVERAGE	0.999	20.417	21.212	21.617	18.964	82.211

Treatment Tank Technology 7
In-ground, stainless steel, 3,700 gallons
Corrosion Protection, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.963	7.280	0.347	3.627	0.206	11.460
2	.012	546.100	604.000	602.000	540.100	2292.200
3	.008	155.025	631.000	624.000	559.000	1969.025
4	.008	828.000	915.000	906.000	815.400	3464.400
5	.004	0.000	0.000	0.000	0.000	0.000
6	.004	0.217	624.300	926.000	832.700	2383.217
WEIGHTED AVERAGE	0.999	21.429	22.447	26.661	21.006	91.543

Treatment Tank Technology 7
In-ground, stainless steel, 3,700 gallons
Partial Containment with Ground-water Monitoring, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.550	0.000	0.000	0.000	0.165	0.165
2	.380	0.000	0.000	0.000	0.000	0.000
3	.050	110.300	122.600	126.500	113.900	473.300
4	.008	144.700	620.000	620.000	558.000	1942.700
5	.008	368.800	406.000	406.000	365.400	1546.199
6	.004	813.000	895.000	895.000	805.600	3408.600
WEIGHTED AVERAGE	1.000	12.875	17.918	18.113	16.395	65.301

EXHIBIT A-4 (continued)

REPRESENTATIVE RELEASE PROFILES FOR TREATMENT TANKS

Treatment Tank Technology 7
In-ground, stainless steel, 3,700 gallons
Secondary Containment, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.812	0.000	0.315	0.072	0.035	0.422
2	.152	0.000	0.000	0.000	0.000	0.000
3	.016	17.900	0.000	0.194	0.088	18.182
4	.008	0.000	0.000	0.000	17.900	17.900
5	.008	0.000	0.000	1.650	32.900	34.550
6	.004	0.000	0.003	70.112	0.117	70.232
WEIGHTED AVERAGE	1.000	0.286	0.256	0.355	0.437	1.334

EXHIBIT A-5

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 8 and Accumulation Tank Technology 17
Above-ground, on cradles, carbon steel, 5,500 gallons
Baseline, Aqueous and Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.759	1.730	1.316	0.000	2.620	5.666
2	.127	0.926	1.378	2.554	5.750	10.608
3	.051	3.620	8.677	3.500	2.499	18.296
4	.042	0.658	1.080	0.000	6.923	8.661
5	.017	0.000	0.000	0.000	0.000	0.000
6	.004	13.431	25.400	6.214	0.544	45.589
WEIGHTED AVERAGE	1.000	1.697	1.763	0.528	3.139	7.127

Storage Tank Technology 8 and Accumulation Tank Technology 17
Above-ground, on cradles, carbon steel, 5,500 gallons
Secondary Containment, Aqueous and Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.612	0.000	0.000	0.000	0.000	0.000
2	.344	0.000	0.090	0.000	0.000	0.090
3	.016	10.400	0.000	0.000	0.325	10.725
4	.012	0.000	10.400	0.000	0.000	10.400
5	.008	0.000	0.021	0.000	10.400	10.421
6	.008	0.000	0.000	10.400	0.000	10.400
WEIGHTED AVERAGE	1.000	0.166	0.156	0.083	0.088	0.494

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Baseline, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.800	0.000	1.780	52.150	287.800	341.730
2	.147	910.000	1941.000	3364.000	5170.000	11385.000
3	.027	19580.000	19860.000	20480.000	21630.000	81550.000
4	.022	4016.000	6870.000	10540.000	14960.000	36386.000
5	.004	6662.000	13070.000	21620.000	6524.398	47876.398
WEIGHTED AVERAGE	1.000	777.430	1026.390	1407.548	1929.457	5140.824

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Baseline, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.886	4.575	46.653	279.100	646.600	976.927
2	.066	1416.000	3450.000	6390.000	10240.000	21496.000
3	.031	16950.000	16950.000	16960.000	17200.000	68060.000
4	.013	25980.000	26030.000	26060.000	26110.000	104180.000
5	.004	9551.898	26310.000	26460.000	26620.000	88941.875
WEIGHTED AVERAGE	1.000	998.906	1238.114	1639.401	2227.837	6104.258

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Corrosion Protection, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.840	185.100	253.900	324.400	396.700	1160.100
2	.062	2778.000	4326.000	6220.000	8470.000	21794.000
3	.053	0.000	0.000	0.000	0.000	0.000
4	.027	19550.000	19550.000	19560.000	19550.000	78210.000
5	.013	3827.000	8120.000	14040.000	21600.000	47587.000
6	.004	6662.000	13060.000	21620.000	6522.719	47864.719
WEIGHTED AVERAGE	0.999	931.969	1167.137	1455.255	1693.108	5247.469

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Corrosion Protection, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.864	215.600	308.900	431.600	634.000	1590.100
2	.053	0.000	0.000	0.000	0.000	0.000
3	.035	2723.000	5760.000	9920.000	15250.000	33653.000
4	.031	15250.000	15250.000	15250.000	15250.000	61000.000
5	.013	25980.000	26030.000	26060.000	26110.000	104180.000
6	.004	9551.898	26310.000	26460.000	26620.000	88941.875
WEIGHTED AVERAGE	1.000	1130.281	1384.869	1637.471	2000.186	6152.801

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Partial Containment with Ground-water Monitoring, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.591	0.000	182.480	599.400	1439.000	2220.880
2	.320	0.000	0.000	0.000	0.000	0.000
3	.040	17600.000	17600.000	17600.000	17600.000	70400.000
4	.040	2495.000	5307.000	8470.000	12690.000	28962.000
5	.004	14070.000	19575.000	0.000	0.000	33645.000
6	.004	24650.000	24650.000	24650.000	13100.000	87050.000
WEIGHTED AVERAGE	0.999	958.679	1201.025	1495.645	2114.448	5769.797

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Partial Containment with Ground-water Monitoring, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.583	0.000	185.900	518.700	1197.000	1901.600
2	.316	0.000	0.000	0.000	0.000	0.000
3	.061	9950.000	9950.000	9950.000	9990.000	39840.000
4	.026	19750.000	19750.000	19750.000	19750.000	79000.000
5	.009	8580.000	24900.000	24900.000	24900.000	83280.000
6	.004	68.100	5192.598	26710.000	27730.000	59700.695
WEIGHTED AVERAGE	0.999	1197.942	1473.700	1753.792	2155.760	6581.191

Storage Tank Technology 9 and Accumulation Tank Technology 18
Above-ground, ongrade, carbon steel, 210,000 gallons
Secondary Containment, Aqueous and Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.680	0.000	0.000	0.000	0.000	0.000
2	.292	6.300	6.343	0.159	0.000	12.802
3	.012	0.000	397.000	0.000	0.000	397.000
4	.008	0.000	0.000	397.000	0.000	397.000
5	.004	0.000	0.000	397.000	0.010	397.010
6	.004	0.000	0.000	397.000	0.000	397.000
WEIGHTED AVERAGE	1.000	1.840	6.616	6.398	0.000	14.854

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Baseline, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.366	10.500	0.191	5.050	0.000	15.741
2	.218	0.225	5.180	46.160	11.000	62.565
3	.206	0.256	0.280	4.816	37.230	42.582
4	.181	16.510	16.420	0.000	0.002	32.932
5	.021	19.420	31.600	43.970	50.360	145.350
6	.008	0.000	0.000	0.000	0.000	0.000
WEIGHTED AVERAGE	1.000	7.341	4.892	13.827	11.125	37.185

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Baseline, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.262	0.000	0.000	0.003	5.345	5.348
2	.221	0.000	19.477	52.370	0.000	71.847
3	.212	0.188	0.632	19.310	49.630	69.760
4	.204	10.710	39.640	0.000	1.944	52.294
5	.096	45.350	0.077	0.005	0.396	45.828
6	.004	0.000	0.000	0.000	0.000	0.000
WEIGHTED AVERAGE	0.999	6.578	12.532	15.669	12.357	47.136

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Corrosion Protection, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.806	0.490	0.490	0.490	0.490	1.960
2	.068	24.900	0.000	0.000	0.000	24.900
3	.055	0.000	0.000	0.000	0.000	0.000
4	.042	0.002	0.005	0.451	27.111	27.569
5	.017	20.270	30.670	43.350	56.100	150.390
6	.013	32.140	59.020	17.020	0.000	108.180
WEIGHTED AVERAGE	1.001	2.851	1.684	1.372	2.487	8.394

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Corrosion Protection, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.762	0.519	0.540	0.565	0.587	2.211
2	.092	33.670	0.000	1.570	0.000	35.240
3	.054	0.000	0.000	0.000	0.000	0.000
4	.054	0.000	0.000	1.424	25.240	26.664
5	.025	15.700	22.380	31.170	40.060	109.310
6	.012	0.000	3.356	37.790	0.000	41.146
WEIGHTED AVERAGE	0.999	3.886	1.011	1.885	2.812	9.593

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Secondary Containment, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.700	0.001	0.000	0.020	0.000	0.021
2	.280	0.000	0.000	0.000	0.000	0.000
3	.008	7.574	0.002	0.462	0.000	8.038
4	.004	0.018	7.577	0.000	0.000	7.595
5	.004	15.160	0.000	0.000	0.000	15.160
6	.004	0.020	0.000	0.000	7.570	7.590
WEIGHTED AVERAGE	1.000	0.122	0.030	0.018	0.030	0.200

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Secondary Containment, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.700	0.001	0.000	0.020	0.000	0.021
2	.280	0.000	0.000	0.000	0.000	0.000
3	.008	7.574	0.002	0.360	0.000	7.936
4	.004	0.018	7.577	0.000	0.000	7.595
5	.004	15.160	0.000	0.000	0.000	15.160
6	.004	0.020	0.000	0.000	7.570	7.590
WEIGHTED AVERAGE	1.000	0.122	0.030	0.017	0.030	0.200

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Leak Testing with Ground-water Monitoring, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.937	0.375	0.000	0.525	0.000	0.900
2	.025	4.464	1.050	7.231	0.787	13.532
3	.017	2.840	10.100	0.430	0.000	13.370
4	.008	0.000	0.000	0.000	0.000	0.000
5	.008	15.100	0.000	0.000	0.000	15.100
6	.004	16.900	0.000	1.800	0.322	19.022
WEIGHTED AVERAGE	0.999	0.700	0.198	0.687	0.021	1.606

Storage Tank Technology 10 and Accumulation Tank Technology 19
Underground, carbon steel, 4,000 gallons
Leak Testing with Ground-water Monitoring, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.950	0.140	0.000	0.273	0.000	0.413
2	.012	1.820	15.100	0.000	0.000	16.920
3	.012	0.001	0.000	0.966	11.120	12.087
4	.008	0.000	0.000	0.000	0.000	0.000
5	.008	15.100	0.000	0.000	0.000	15.100
6	.008	20.221	0.000	0.854	7.078	28.153
WEIGHTED AVERAGE	0.998	0.437	0.181	0.278	0.190	1.086

Storage Tank Technology 11 and Accumulation Tank Technology 20
Underground, fiberglass reinforced plastic, 4,000 gallons
Baseline, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.866	0.450	1.150	0.000	0.780	2.380
2	.052	0.000	0.000	0.000	0.000	0.000
3	.026	5.062	0.012	2.930	0.000	8.004
4	.022	0.485	0.455	0.455	17.191	18.586
5	.017	0.000	0.000	15.100	0.000	15.100
6	.017	7.588	0.005	0.005	0.005	7.603
WEIGHTED AVERAGE	1.000	0.661	1.006	0.343	1.054	3.064

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 11 and Accumulation Tank Technology 20
Underground, fiberglass reinforced plastic, 4,000 gallons
Baseline, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.836	0.226	0.387	0.390	0.390	1.393
2	.052	0.000	0.000	0.000	0.000	0.000
3	.047	7.584	0.005	0.005	0.005	7.599
4	.026	5.062	0.012	2.930	0.000	8.004
5	.022	0.366	0.325	0.325	17.135	18.151
6	.017	0.085	0.085	15.168	0.000	15.338
WEIGHTED AVERAGE	1.000	0.686	0.333	0.667	0.703	2.390

Storage Tank Technology 11 and Accumulation Tank Technology 20
Underground, fiberglass reinforced plastic, 4,000 gallons
Secondary Containment, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.680	0.020	0.003	0.000	0.000	0.023
2	.300	0.000	0.000	0.000	0.000	0.000
3	.008	0.015	0.000	7.573	0.007	7.595
4	.004	0.000	10.093	0.000	0.000	10.093
5	.004	15.160	0.000	0.000	0.000	15.160
6	.004	0.018	7.578	0.000	0.000	7.596
WEIGHTED AVERAGE	1.000	0.074	0.073	0.061	0.000	0.208

Storage Tank Technology 11 and Accumulation Tank Technology 20
Underground, fiberglass reinforced plastic, 4,000 gallons
Secondary Containment, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.676	0.020	0.003	0.000	0.000	0.023
2	.304	0.000	0.000	0.000	0.000	0.000
3	.008	0.015	0.000	7.573	0.007	7.595
4	.004	0.000	10.093	0.000	0.000	10.093
5	.004	15.160	0.000	0.000	0.000	15.160
6	.004	0.018	7.578	0.000	0.000	7.596
WEIGHTED AVERAGE	1.000	0.074	0.073	0.061	0.000	0.208

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 11 and Accumulation Tank Technology 20
Underground, fiberglass reinforced plastic, 4,000 gallons
Leak Testing with Ground-water Monitoring, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.787	0.000	0.000	0.232	0.000	0.232
2	.089	0.000	0.000	0.000	0.000	0.000
3	.034	0.000	7.570	0.000	0.000	7.570
4	.034	10.556	0.000	2.080	0.000	12.636
5	.030	0.000	6.830	0.000	0.000	6.830
6	.026	0.000	0.000	0.000	9.290	9.290
WEIGHTED AVERAGE	1.000	0.359	0.462	0.253	0.242	1.316

Storage Tank Technology 11 and Accumulation Tank Technology 20
Underground, fiberglass reinforced plastic, 4,000 gallons
Leak Testing with Ground-water Monitoring, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.787	0.000	0.000	0.232	0.000	0.232
2	.089	0.000	0.000	0.000	0.000	0.000
3	.034	0.000	7.570	0.000	0.001	7.571
4	.034	10.556	0.000	2.080	0.000	12.636
5	.030	0.000	6.830	0.000	0.000	6.830
6	.026	0.000	0.000	0.000	8.470	8.470
WEIGHTED AVERAGE	1.000	0.359	0.462	0.253	0.220	1.295

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Baseline, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.820	0.505	0.505	0.505	0.505	2.020
2	.084	0.000	0.000	0.000	0.000	0.000
3	.071	0.000	0.000	4.327	36.100	40.427
4	.013	0.000	5.270	44.460	17.900	67.630
5	.008	0.275	0.275	15.310	0.000	15.860
6	.004	50.990	66.000	15.002	0.010	132.002
WEIGHTED AVERAGE	1.000	0.620	0.749	1.482	3.210	6.061

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Baseline, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.820	0.380	0.380	0.380	0.380	1.520
2	.084	0.000	0.000	0.000	0.000	0.000
3	.050	0.000	0.000	0.979	23.760	24.739
4	.029	0.005	1.989	20.080	38.810	60.884
5	.013	0.000	4.510	31.930	58.190	94.630
6	.004	36.430	46.760	57.000	67.400	207.590
WEIGHTED AVERAGE	1.000	0.457	0.615	1.586	3.651	6.310

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Corrosion Protection, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.883	0.507	0.510	0.510	0.510	2.037
2	.079	0.000	0.000	0.000	0.000	0.000
3	.017	0.604	0.000	7.570	0.000	8.174
4	.013	0.000	10.300	0.381	0.180	10.861
5	.004	16.900	0.000	10.100	0.322	27.322
6	.004	50.990	66.000	15.002	0.010	132.002
WEIGHTED AVERAGE	1.000	0.730	0.848	0.684	0.454	2.716

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Corrosion Protection, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.866	0.380	0.380	0.380	0.380	1.520
2	.079	0.000	0.000	0.000	0.000	0.000
3	.029	0.003	6.123	0.005	0.005	6.136
4	.013	0.681	0.010	34.972	7.410	43.073
5	.008	0.000	1.350	10.100	0.004	11.454
6	.004	36.430	46.760	57.000	67.400	207.590
WEIGHTED AVERAGE	0.999	0.484	0.705	1.093	0.695	2.976

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Secondary Containment, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.640	0.001	0.000	0.020	0.000	0.021
2	.340	0.000	0.000	0.000	0.000	0.000
3	.008	0.020	0.000	0.000	7.570	7.590
4	.004	0.018	7.570	0.000	0.000	7.588
5	.004	7.574	0.002	0.012	0.000	7.588
6	.004	15.160	0.000	0.000	0.000	15.160
WEIGHTED AVERAGE	1.000	0.092	0.030	0.013	0.061	0.196

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Secondary Containment, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.636	0.001	0.000	0.020	0.000	0.021
2	.344	0.000	0.000	0.000	0.000	0.000
3	.008	0.015	0.000	7.573	0.007	7.595
4	.004	0.018	7.570	0.000	0.000	7.588
5	.004	7.574	0.002	0.012	0.000	7.588
6	.004	15.160	0.000	0.000	0.000	15.160
WEIGHTED AVERAGE	1.000	0.092	0.030	0.073	0.000	0.195

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Leak Testing with Ground-water Monitoring, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.843	0.000	0.000	0.146	0.000	0.146
2	.070	0.000	0.000	0.000	0.000	0.000
3	.029	0.000	0.000	0.000	2.780	2.780
4	.025	0.000	0.000	5.050	0.328	5.378
5	.017	0.000	2.990	0.000	7.560	10.550
6	.017	0.001	7.570	0.000	0.000	7.571
WEIGHTED AVERAGE	1.001	0.000	0.180	0.249	0.217	0.646

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 12 and Accumulation Tank Technology 21
Underground, stainless steel, 4,000 gallons
Leak Testing with Ground-water Monitoring, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.839	1.220	0.000	0.000	0.012	1.232
2	.070	0.000	0.000	0.000	0.000	0.000
3	.058	0.000	0.160	0.701	6.490	7.351
4	.017	2.183	0.010	0.688	2.820	5.701
5	.012	1.020	0.000	0.165	11.009	12.194
6	.004	0.000	15.100	0.000	0.000	15.100
WEIGHTED AVERAGE	1.000	1.073	0.070	0.054	0.567	1.764

Storage Tank Technology 13 and Accumulation Tank Technology 22
In-ground, concrete, 2,100 gallons
Baseline, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.725	0.340	1.332	0.368	0.340	2.380
2	.098	0.378	1.651	2.314	1.357	5.700
3	.078	1.862	0.340	0.340	2.992	5.534
4	.053	0.340	0.340	2.522	0.340	3.542
5	.045	0.816	1.212	3.152	3.192	8.372
WEIGHTED AVERAGE	0.999	0.484	1.227	0.796	0.775	3.280

Storage Tank Technology 13 and Accumulation Tank Technology 22
In-ground, concrete, 2,100 gallons
Baseline, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.725	0.569	0.230	1.116	0.231	2.146
2	.098	0.230	0.279	0.230	0.843	1.582
3	.078	0.263	0.230	2.936	0.230	3.659
4	.066	0.535	0.460	0.259	2.834	4.088
5	.033	1.155	0.243	3.331	0.230	4.959
WEIGHTED AVERAGE	1.000	0.529	0.250	1.188	0.463	2.430

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 13 and Accumulation Tank Technology 22
In-ground, concrete, 2,100 gallons
Partial Containment with Ground-water Monitoring, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.943	0.340	0.340	0.340	0.340	1.360
2	.024	0.340	0.340	2.992	0.340	4.012
3	.012	0.340	4.312	0.340	0.340	5.332
4	.012	0.340	0.340	4.312	0.340	5.332
5	.008	0.340	4.312	0.340	0.340	5.332
WEIGHTED AVERAGE	0.999	0.340	0.419	0.451	0.340	1.549

Storage Tank Technology 13 and Accumulation Tank Technology 22
In-ground, Concrete, 2,100 gallons
Partial Containment with Ground-water Monitoring, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.943	0.230	0.230	0.230	0.230	0.920
2	.024	0.230	0.230	2.884	0.230	3.574
3	.012	0.230	4.204	0.230	0.230	4.894
4	.012	0.230	0.230	4.204	0.230	4.894
5	.008	0.230	4.204	0.230	0.230	4.894
WEIGHTED AVERAGE	0.999	0.230	0.309	0.341	0.230	1.110

Storage Tank Technology 13 and Accumulation Tank Technology 22
In-ground, concrete, 2,100 gallons
Secondary Containment, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.848	0.000	0.000	0.000	0.000	0.000
2	.120	0.000	0.015	0.010	0.000	0.025
3	.016	0.000	3.970	0.008	0.000	3.978
4	.008	0.000	0.011	3.970	0.000	3.981
5	.004	0.001	0.000	0.000	3.970	3.971
6	.004	0.000	0.000	0.000	3.970	3.970
WEIGHTED AVERAGE	1.000	0.000	0.065	0.033	0.032	0.130

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 13 and Accumulation Tank Technology 22
In-ground, concrete, 2,100 gallons
Secondary Containment, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.848	0.000	0.000	0.000	0.000	0.000
2	.120	0.000	0.015	0.010	0.000	0.025
3	.016	0.000	3.970	0.008	0.000	3.978
4	.008	0.000	0.011	3.970	0.000	3.981
5	.004	0.001	0.000	0.000	3.970	3.971
6	.004	0.000	0.000	0.000	3.970	3.970
WEIGHTED AVERAGE	1.000	0.000	0.065	0.033	0.032	0.130

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Baseline, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.538	2.650	0.001	2.650	0.905	6.206
2	.188	0.085	0.477	6.636	0.000	7.198
3	.159	0.000	0.000	0.183	6.400	6.583
4	.101	6.897	4.643	1.100	1.471	14.111
5	.010	7.450	0.052	3.350	25.600	36.452
6	.005	0.000	0.000	0.000	0.000	0.000
WEIGHTED AVERAGE	1.001	2.213	0.560	2.847	1.909	7.528

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Baseline, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.479	6.660	3.790	0.000	0.122	10.572
2	.202	2.222	0.000	0.082	8.640	10.944
3	.178	0.000	0.000	8.322	1.141	9.463
4	.117	18.860	0.902	3.048	2.721	25.531
5	.019	15.286	28.284	1.010	0.023	44.603
6	.005	0.000	0.000	0.000	0.000	0.000
WEIGHTED AVERAGE	1.000	6.136	2.458	1.874	2.326	12.794

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Corrosion Protection, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.784	0.211	0.205	0.072	0.637	1.125
2	.063	0.264	0.000	0.593	3.370	4.227
3	.063	0.087	0.000	5.380	0.519	5.986
4	.048	5.372	0.026	0.000	0.366	5.764
5	.038	0.000	0.000	0.000	0.000	0.000
6	.005	16.069	7.909	0.011	0.128	24.117
WEIGHTED AVERAGE	1.001	0.526	0.202	0.433	0.763	1.923

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Corrosion Protection, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.714	0.000	0.000	0.106	0.404	0.510
2	.174	0.000	1.447	2.650	0.329	4.426
3	.038	0.000	0.000	0.000	0.000	0.000
4	.038	0.084	0.000	7.740	0.519	8.343
5	.033	11.670	0.000	0.000	0.000	11.670
6	.005	12.826	18.970	0.010	0.128	31.934
WEIGHTED AVERAGE	1.002	0.452	0.347	0.831	0.366	1.996

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Partial Containment with Ground-water Monitoring, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.557	0.767	0.000	0.000	0.000	0.767
2	.127	0.000	0.000	0.000	0.000	0.000
3	.109	0.000	0.000	1.810	7.420	9.230
4	.095	0.000	9.700	0.000	0.000	9.700
5	.090	0.000	0.488	12.610	0.000	13.098
6	.023	13.376	13.370	0.000	0.000	26.746
WEIGHTED AVERAGE	1.001	0.735	1.273	1.332	0.809	4.149

EXHIBIT A-5 (continued)

REPRESENTATIVE RELEASE PROFILES FOR STORAGE/ACCUMULATION TANKS

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Partial Containment with Ground-water Monitoring, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.476	0.000	0.000	1.160	0.000	1.160
2	.148	8.080	1.940	0.000	0.192	10.212
3	.131	0.000	11.470	0.000	0.000	11.470
4	.122	0.000	0.000	0.000	0.000	0.000
5	.096	0.000	0.000	7.410	10.430	17.840
6	.026	9.211	30.370	8.980	0.000	48.561
WEIGHTED AVERAGE	0.999	1.435	2.579	1.497	1.030	6.541

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Secondary Containment, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.732	0.000	0.000	0.000	0.000	0.000
2	.204	0.000	0.193	0.000	0.000	0.193
3	.020	0.000	0.000	2.650	0.000	2.650
4	.020	0.335	2.650	0.000	0.000	2.985
5	.016	0.000	11.780	2.580	0.000	14.360
6	.008	0.000	3.970	0.000	0.000	3.970
WEIGHTED AVERAGE	1.000	0.007	0.313	0.094	0.000	0.414

Storage Tank Technology 14 and Accumulation Tank Technology 23
In-ground, carbon steel, 2,100 gallons
Secondary Containment, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.732	0.000	0.000	0.000	0.000	0.000
2	.200	0.000	0.000	0.105	0.000	0.105
3	.028	0.312	2.650	0.000	0.000	2.962
4	.024	0.000	2.650	0.000	0.000	2.650
5	.012	0.000	9.210	10.290	0.000	19.500
6	.004	0.000	11.120	21.450	0.000	32.570
WEIGHTED AVERAGE	1.000	0.009	0.293	0.230	0.000	0.532

EXHIBIT A-6

REPRESENTATIVE RELEASE PROFILES FOR SQG TANKS

Small Quantity Generator Tank Technology 15
Above-ground, carbon steel, 200 gallons
Baseline, Aqueous and Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.672	0.000	0.252	0.000	0.126	0.378
2	.097	0.126	0.224	0.504	0.126	0.980
3	.076	0.378	0.279	0.378	0.379	1.414
4	.063	0.135	0.379	0.000	0.379	0.893
5	.059	0.145	0.378	0.128	0.000	0.651
6	.034	0.000	0.000	0.000	0.000	0.000
WEIGHTED AVERAGE	1.001	0.058	0.258	0.085	0.150	0.551

Small Quantity Generator Tank Technology 15
Above-ground, carbon steel, 200 gallons
Secondary Containment, Aqueous and Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.668	0.000	0.000	0.000	0.000	0.000
2	.288	0.000	0.000	0.033	0.000	0.033
3	.016	0.000	0.378	0.000	0.000	0.378
4	.012	0.000	0.378	0.000	0.000	0.378
5	.008	0.000	0.000	0.000	0.378	0.378
6	.008	0.378	0.000	0.000	0.000	0.378
WEIGHTED AVERAGE	1.000	0.003	0.011	0.010	0.003	0.026

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Baseline, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.735	0.000	0.000	0.000	1.200	1.200
2	.099	0.734	0.758	0.093	0.000	1.585
3	.076	0.000	1.450	0.756	0.000	2.206
4	.067	0.000	0.000	0.000	0.631	0.631
5	.018	0.000	0.000	0.000	0.000	0.000
6	.004	3.920	0.114	1.340	0.017	5.391
WEIGHTED AVERAGE	0.999	0.088	0.186	0.072	0.924	1.270

EXHIBIT A-6 (continued)

REPRESENTATIVE RELEASE PROFILES FOR SQG TANKS

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Baseline, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.585	0.581	0.000	0.000	1.374	1.955
2	.135	0.000	0.000	2.533	0.000	2.533
3	.127	0.000	2.373	0.000	0.000	2.373
4	.105	0.000	1.038	0.727	0.000	1.765
5	.031	2.355	0.000	0.000	0.000	2.355
6	.017	0.000	0.000	0.000	0.000	0.000
WEIGHTED AVERAGE	1.000	0.413	0.410	0.418	0.804	2.045

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Corrosion Protection, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.825	0.040	0.040	0.040	0.040	0.160
2	.130	0.000	0.000	0.000	0.000	0.000
3	.018	0.000	0.000	0.000	0.631	0.631
4	.018	0.730	0.019	0.030	0.030	0.809
5	.004	3.920	0.000	0.000	0.017	3.937
6	.004	0.079	1.502	1.010	0.068	2.659
WEIGHTED AVERAGE	0.999	0.062	0.039	0.038	0.045	0.184

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Corrosion Protection, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.800	0.009	0.035	0.035	0.065	0.144
2	.126	0.000	0.000	0.000	0.000	0.000
3	.048	0.756	0.000	0.033	0.040	0.829
4	.013	0.000	0.000	0.012	1.451	1.463
5	.009	0.000	1.561	0.000	0.000	1.561
6	.004	5.352	1.460	0.000	0.017	6.829
WEIGHTED AVERAGE	1.000	0.065	0.048	0.030	0.073	0.215

EXHIBIT A-6 (continued)

REPRESENTATIVE RELEASE PROFILES FOR SQG TANKS

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Secondary Containment, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.892	0.000	0.000	0.000	0.000	0.000
2	.072	0.000	0.012	0.000	0.000	0.012
3	.012	0.000	0.000	0.379	0.000	0.379
4	.008	0.000	0.000	0.000	0.378	0.378
5	.008	0.000	0.000	0.378	0.000	0.378
6	.008	0.000	0.506	0.000	0.000	0.506
WEIGHTED AVERAGE	1.000	0.000	0.005	0.008	0.003	0.016

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Secondary Containment, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.892	0.000	0.000	0.000	0.000	0.000
2	.076	0.000	0.012	0.000	0.000	0.012
3	.008	0.000	0.000	0.000	0.378	0.378
4	.008	0.000	0.000	0.378	0.000	0.378
5	.008	0.000	0.364	0.000	0.000	0.364
6	.008	0.000	0.000	0.379	0.000	0.379
WEIGHTED AVERAGE	1.000	0.000	0.004	0.006	0.003	0.013

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Leak Testing with Ground-water Monitoring, Toluene

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.692	0.000	0.000	0.108	0.000	0.108
2	.093	0.000	1.153	0.910	0.000	2.063
3	.088	0.000	1.935	0.000	0.401	2.336
4	.084	0.116	0.000	0.000	1.264	1.380
5	.031	0.000	0.000	0.000	1.723	1.723
6	.013	0.000	0.000	0.000	0.000	0.000
WEIGHTED AVERAGE	1.001	0.010	0.278	0.159	0.195	0.641

EXHIBIT A-6 (continued)

REPRESENTATIVE RELEASE PROFILES FOR SQG TANKS

Small Quantity Generator Tank Technology 16
Underground, carbon steel, 200 gallons
Leak Testing with Ground-water Monitoring, Aqueous

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.649	0.000	0.000	0.000	0.121	0.121
2	.126	0.000	0.000	2.859	0.000	2.859
3	.087	2.063	0.000	0.000	0.000	2.063
4	.065	0.000	0.000	0.000	2.912	2.912
5	.061	0.007	0.778	1.915	0.000	2.700
6	.013	0.000	0.000	0.000	0.000	0.000
WEIGHTED AVERAGE	1.001	0.180	0.047	0.477	0.268	0.972

APPENDIX B

SUPPLEMENTARY ANALYSIS OF ELEVEN REGULATORY SCENARIOS

This appendix presents the results of our supplementary analysis to the Hazardous Waste Tank Risk Analysis. In this supplementary analysis, we compare chronic human health risk estimates for eleven regulatory scenarios. For this analysis, we compare the regulatory scenarios applied to a single tank technology, located in a specific hydrogeologic setting and containing a single waste stream. This approach minimizes the number of variables included in the analysis and allows for a more straightforward comparison to be made.

The appendix is divided into five major sections. The first section briefly describes each of the eleven regulatory scenarios included in the analysis, and outlines assumptions that were made to incorporate these scenarios in the Hazardous Waste Tank Failure (HWTF) model and the Tank Risk Analysis Model (TRAM). The second section describes the model tank technology, waste stream, and hydrogeologic setting we selected for this analysis. The third section of the memorandum presents the HWTF model results for the eleven analyzed regulatory scenarios, while the fourth section presents TRAM risk estimates for the eleven scenarios. In the fifth and final section we describe how we modeled excavation zone monitoring.

We would like to stress that these results are preliminary, and that the short time frame required for this supplementary analysis has forced us to use model algorithms that have not been extensively reviewed. Also, as was the case with the Hazardous Waste Tank Risk Analysis, lack of data has forced us to make major assumptions in some instances, and the effect of these assumptions on the outcome of the analysis has not yet been quantified.

B.1 OVERVIEW OF SUPPLEMENTARY ANALSYIS

For this supplementary analysis, we have developed relative risk estimates for a single hazardous waste tank technology under eleven regulatory scenarios. These regulatory scenarios are as follows:

- Existing tank regulated under baseline;
- New tank regulated under baseline;
- Existing tank retrofit with corrosion protection;
- Existing tank retrofit with corrosion protection and leak tested semi-annually;
- Existing tank replaced with new tank equipped with full secondary containment;

- Existing tank replaced with new tank equipped with full secondary containment and corrosion protection;
- Existing tank leak tested semi-annually;
- Existing tank retrofit with excavation zone monitoring;
- Existing tank retrofit with corrosion protection and excavation zone monitoring;
- Existing tank replaced with a new tank equipped with excavation zone monitoring; and
- Existing tank replaced with a new tank equipped with corrosion protection and excavation zone monitoring.

Each of these scenarios is described in greater detail below.

Existing Tank, Baseline. In this scenario, we assume that hazardous waste tanks are managed and operated in compliance with existing regulations. These regulations basically involve good operating practices, such as regular visual inspections and waste compatibility with the tank material. Under this scenario there are no technical requirements that prevent releases from primary containment, nor are there requirements that would assist in the early detection of releases from underground or in-ground hazardous waste tanks.

Under the baseline scenario, releases from hazardous waste tanks are only detected if: (1) the leak is above-ground and large enough to be visually detected; or (2) the leak is so large that at the time the contents are normally removed it is obvious that the tank is not as full as it should be. Assumptions used in this analysis for casual leak detection are identical to those used in the Hazardous Waste Tank Risk Analysis; leaks larger than 25 percent of the tank operating capacity are assumed to be detected for all tanks with the exception of small quantity generators (SQG) tanks. For SQG tanks, 100 percent of the tank volume must be released before a leak is detected through casual inventory monitoring.[1]

For the baseline scenario, the model tank is assumed to be an existing tank, whose age is equal to the median tank age for the national population of the particular tank technology being analyzed. For example, the median age for underground, 4000 gallon, carbon steel storage tanks is seven years; consequently, the underground, 4000 gallon, carbon steel storage tank considered in our analysis is seven years old at the onset of the 20-year modeling period.

New Tank, Baseline. This scenario is identical to the baseline scenario outlined above, except rather than using the median age of the national population to represent the age of a particular tank technology, each tank is assumed to be new at the beginning of the 20-year modeling period.

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[1] See Section 2.3 of this report for a detailed discussion of inventory monitoring assumptions.

Existing Tank Retrofit with Corrosion Protection. In this scenario, all metal tank systems that have some portion of the tank or ancillary equipment in contact with the soil are assumed to be fitted with cathodic protection. (Cathodic protection is assumed to be provided by an impressed current system for these tanks.) Thus, the probability of failure due to corrosion is reduced; however the probability of all other failure events remains the same. It is important to note that this scenario does not include any protective measure that would aid in the rapid detection of leaks (e.g., excavation zone monitoring, leak testing, or ground-water monitoring).

Existing Tank Retrofit with Corrosion Protection and Leak Tested Semi-Annually. In addition to providing metal tank systems with impressed current cathodic protection to prevent corrosion, this scenario assumes that all underground tanks are leak tested semi-annually, using a hydrostatic pressure test. Currently, there are no proven leak tests for tanks containing hazardous wastes, and therefore we assume that the tank is emptied, cleaned, and filled with water in order to perform the leak test.

In addition to the previously mentioned assumptions regarding corrosion protection, this scenario makes several key assumptions with respect to leak testing. First, it is important to note that leak tests are only reliable for leaks greater than some minimum size; thus the test will fail to detect very small leaks. For this analysis we assume that the leak test used is capable of detecting leaks as small as 0.1 gallons/hour. Although there is some probability that a leak test will fail even if the leak is large enough to be detected, in this analysis we assume that leak testing is 100 percent effective due to lack of data. Finally, the frequency of leak testing is important, because the more frequently a leak test is performed, the more likely a leak will be detected before excessive environmental damage or adverse human health effects occur. In this analysis we assumed semi-annual leak testing, as presented in the proposed rule (50 Federal Register, June 26, 1985).

Existing Tank Replaced with New Tank Equipped with Full Secondary Containment. Under this scenario, we assume that hazardous waste tank systems are replaced by new tank systems equipped with full secondary containment designed to prevent leaks from escaping to the environment. For this analysis, we assume that secondary containment is provided for the tank by the installation of a double-walled tank. Secondary containment for underground pipes is provided by installing double-walled pipes. Also, the new tank is assumed to be equipped with an interstitial leak monitoring system that allows for the rapid detection of leaks that have accumulated within the secondary containment system. This leak detection system is assumed to be 90 percent effective. Upon replacement of the tank we assume that all contaminated soil is removed and that the tank is in a pristine environment.

Existing Tank Replaced with New Tank Equipped with Full Secondary Containment and Corrosion Protection. This scenario assumes that existing metal tank systems are replaced with new tanks equipped with full secondary containment (i.e., double-walled tank and double-walled pipe). In addition to interstitial leak monitoring systems, these tanks are also equipped with impressed current cathodic protection to prevent external corrosion of the outer wall of the secondary containment system. All assumptions noted previously for secondary containment and corrosion protection also apply to this scenario.

Existing Tank Leak Tested Semi-Annually. In this scenario, we assume that an existing tank is leak tested semi-annually using a hydrostatic pressure test as described above. All of the assumptions with respect to leak testing that were noted earlier also apply to this scenario. It is also important to note that this scenario does not include any protective measure (e.g., corrosion protection, secondary containment) that would decrease the probability of certain failure events.

Existing Tank Retrofit with Excavation Zone Monitoring. This scenario assumes that existing tanks are equipped with an excavation zone monitoring system that allows for rapid detection of leaks through the detection of vapor-phase contaminants migrating through the unsaturated zone surrounding the tank. Some hazardous waste constituents may volatilize after being released from a tank, and may migrate through the unsaturated zone. In this scenario, we predict the migration of vapor-phase contaminants through the excavation zone (which is assumed to consist of homogenous, isotropic sand) to vapor wells that contain sensors that are able to detect low concentrations of these contaminants in the soil atmosphere. When a vapor-phase detection limit for the contaminant of interest is exceeded, we assume that detection occurs. We use detection limits specified by gas phase detection system manufacturers.

Thus, excavation zone monitoring does not prevent releases or minimize the probability of certain failure events, but rather allows for rapid detection of leaks once they occur. There is some probability that a leak will remain undetected by the monitoring system; therefore, we consider excavation zone monitoring to be 90 percent reliable in this analysis. Also, we assume that sensors are inspected monthly, and that failed sensors are replaced during each inspection. This assumption implies that the maximum duration that an excavation zone monitoring system will be in a failed state is one month.

Excavation zone monitoring is an option that was added to the HWTF model for this analysis, and thus, is not documented in the earlier chapters of this report. Therefore, we have included a brief description of the model algorithm and its assumptions in Section B.5 of this appendix.

Existing Tank Retrofit with Corrosion Protection and With Excavation Zone Monitoring. For this scenario, we assume that existing hazardous waste tank systems are equipped with impressed current cathodic protection to prevent corrosion, and with excavation zone monitoring for rapid detection of leaks. All assumptions and limitations noted earlier for corrosion protection and excavation zone monitoring also apply to this scenario.

Existing Tank Replaced with New Tank Equipped with Excavation Zone Monitoring. In this scenario, an existing tank is replaced by a new tank equipped with excavation zone monitoring. All previously mentioned assumptions for excavation zone monitoring also apply to this scenario. In addition, the new tank is assumed to be in a pristine environment.

Existing Tank Replaced with New Tank Equipped with Corrosion Protection and Excavation Zone Monitoring. For this regulatory scenario we assume that an existing tank is replaced with a new tank equipped with both an impressed current cathodic protection system to prevent corrosion, and an excavation zone monitoring system for rapid detection of leaks. Once again, all assumptions noted above for corrosion protection and excavation zone monitoring apply to this scenario.

B.2 MODEL TANK TECHNOLOGY, WASTE STREAM, AND HYDROGEOLOGIC SETTING

For this analysis, we selected a single tank technology, waste stream, and hydrogeologic setting, in order to minimize the number of variables affecting risk. Thus, our major objective in this supplementary analysis was to directly compare different regulatory scenarios for a single situation, rather than for the population of existing tanks as was done in the body of this report.

The tank technology we selected for this analysis is an underground, 4000 gallon, carbon steel, RCRA-permitted storage tank. This tank is provided with full secondary containment by the installation of a double-walled tank of the same size and material, and corrosion protection is provided by an impressed current system. Leak testing for this tank is accomplished by a hydrostatic leak test.

The waste stream chosen for this analysis is EPA waste code U080, dichloromethane. Dichloromethane is a common industrial solvent, and the dichloromethane waste stream was among those identified as commonly storedin hazardous waste tanks in our initial analysis. Also, dichloromethane is highly volatile and is therefore amenable to detection by excavation zone monitoring. It is a carcinogen, but is not highly potent and also degrades at a moderate rate in the subsurface environment; thus, it is a good choice for a risk comparison because: (1) using the TRAM risk model for carcinogens, which assumes no minimum threshold, some finite risk will always be calculated for dichloromethane; and (2) its low potency and the fact that it degrades make it a relatively low risk contaminant, and thus comparative information is not usually lost due to maximum risks being obtained for different regulatory scenarios. Exhibit B-1 presents several parameters that were used to model the detection of dichloromethane using excavation zone monitoring.

For our analysis, we chose ground-water flow field C, with a horizontal ground-water velocity of 100 meters/year, as our generic hydrogeologic setting. This flow field was chosen because it is the most common of the nine generic flow fields considered in our analysis (see Exhibit 4-24), and is therefore most representative of conditions likely to be encountered at tank facilities. Also, the horizontal ground-water velocity in flow field C is optimum in that interactions between dilution, retardation, and degradation for dichloromethane result in moderately high risks for the chemical in this flow field.

EXHIBIT B-1

CHARACTERISTICS OF DICHLOROMETHANE

Parameter	Value
Vapor pressure (mm Hg)	438
Diffusion in air (cm^2/sec)	1.01×10^{-1}
Detectable concentration (ppm)[a]	25

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[a] Source: SENSI-DYNE, Inc. vapor detection literature.

B.3 HAZARDOUS WASTE TANK FAILURE MODEL RESULTS

In this section we present and discuss the results generated by the Hazardous Waste Tank Failure (HWTF) model for the eleven regulatory scenarios considered in this analysis. Two basic types of results are generated by the HWTF model: (1) release volumes (the 20-year series of annual release volumes for each iteration), and (2) the frequencies of the various failure events. We first analyze the failure event frequency data for each of the reguatory scenarios, and then discuss the release volume data.

B.3.1 Frequencies of Failure Events

The HWTF model simulated 238 iterations (an iteration is a simulation of the failure events and release volumes associated with the tank system during a 20-year time horizon) for each regulatory scenario. Based on the results of these 238 iterations, we derived frequency tables that summarize the occurrence of the various failure events.[2] Exhibit B-2 presents the frequencies of events for an existing tank regulated under baseline. The numbers under each event category represent the percent of iterations in which the specified event occurred during a given time frame. For example, between years 2 and 5, in 6.4 percent of the iterations a hose rupture was simulated to occur.

For the regulatory scenarios considered in this analysis failure frequencies are affected by three factors: (1) the age of the modeled tank system; (2) the presence of corrosion protection; and (3) whether the tank is single-walled or double-walled. Other protective measures, such as excavation zone monitoring and leak testing, do not affect failure frequencies. The failure event frequency tables for the remaining regulatory scenarios are presented in Exhibits B-3 through B-12.

The effects of tank age can be seen in the frequencies of pipe and tank corrosion events (other failure events are not affected by tank age). New tanks have fewer corrosion failures than existing tanks (for this analysis, existing tanks are seven years old at the start of the modeling period). This difference occurs mainly because corrosion is a time-dependent process that progresses as the tank ages.

The differences observed in the frequencies of pipe and tank corrosion are also a function of the method by which corrosion events are recorded for new and existing tanks. For existing tanks, corrosion events that occurred prior to the 20-year modeling period are included in the frequency of occurrence for the first model year. Thus, the frequency of corrosion events for the first year also includes the percentage of iterations in which the tank or pipe is already leaking due to corrosion. Consequently, the differences in the frequency of corrosion events between new and existing tanks is due to the summarizing of corrosion failures of existing tanks and pipes prior to model year 1 with other corrosion failures that occur in model year 1.

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[2] For a detailed description of the events, see Section 5.2 of this report.

EXHIBIT B-2

FAILURE FREQUENCIES FOR EXISTING TANK REGULATED UNDER BASELINE a/

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	1ST FAIL	CATAS-TROPH RLS	1ST PIPE REPL	2ND PIPE REPL	3RD PIPE REPL	1ST TANK REPL	2ND TANK REPL	3RD TANK REPL	1ST OVER FLOW	2ND OVER FLOW	TANK INSTAL DEFIC	PIPE INSTAL DEFIC	WELD GASKET INSTAL
1	43.3	0.0	0.4	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.8	0.4
2- 5	37.0	0.4	2.0	0.0	0.0	16.3	0.8	0.0	1.2	0.0	0.0	0.0	0.0
6-10	15.2	1.3	5.0	0.4	0.0	26.4	2.9	0.0	1.3	0.4	0.0	0.0	0.0
11-15	4.1	0.4	4.1	0.4	0.0	16.7	9.3	0.8	1.2	0.0	0.0	0.0	0.0
16-20	0.4	0.0	3.3	0.0	0.0	15.0	14.3	3.8	1.2	0.0	0.4	0.0	0.0
TOTAL	100.0	2.1	14.8	0.8	0.0	78.2	27.3	4.6	4.9	0.4	0.4	0.8	0.4

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	LOOSE HOSE	HOSE RUPTR	WELD/ GASKT FAIL	2ND WG FAIL	1ST PIPE RUPTR	2ND PIPE RUPTR	1ST TANK RUPTR	2ND TANK RUPTR	1ST PIPE CORR	2ND PIPE CORR	1ST TANK CORR	2ND TANK CORR	OTHER EVENTS
1	4.2	0.0	22.3	0.0	4.6	0.0	0.0	0.0	5.5	0.0	16.8	0.0	0.0
2- 5	14.3	6.4	13.8	0.4	2.0	0.0	2.5	0.0	2.5	0.0	26.9	0.4	0.4
6-10	16.4	5.9	9.2	7.1	1.2	0.0	2.5	0.4	0.0	0.0	24.8	4.2	1.2
11-15	11.3	6.3	9.7	5.4	2.8	0.4	2.9	0.0	3.3	0.4	13.4	12.6	2.5
16-20	8.4	6.3	6.0	3.3	2.4	0.0	4.2	0.0	3.7	0.0	5.0	13.9	6.7
TOTAL	54.6	24.9	61.0	16.2	13.0	0.4	12.1	0.4	15.0	0.4	86.9	31.1	10.8

a/ Frequencies are expressed as percent of iterations in which the specified event occurred.

EXHIBIT B-3

FAILURE FREQUENCIES FOR NEW TANK REGULATED UNDER BASELINE a/

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	1ST FAIL	CATAS-TROPH RLS	1ST PIPE REPL	2ND PIPE REPL	3RD PIPE REPL	1ST TANK REPL	2ND TANK REPL	3RD TANK REPL	1ST OVER FLOW	2ND OVER FLOW	TANK INSTAL DEFIC	PIPE INSTAL DEFIC	WELD GASKET INSTAL
1	7.6	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.0
2- 5	40.4	0.4	0.8	0.0	0.0	3.6	0.4	0.0	1.6	0.0	0.0	0.0	0.0
6-10	30.0	0.4	2.0	0.4	0.0	15.2	1.2	0.0	0.8	0.0	0.0	0.0	0.0
11-15	15.2	0.8	4.4	0.0	0.0	19.6	2.4	0.4	0.4	0.0	0.0	0.0	0.0
16-20	6.8	0.4	4.0	0.0	0.0	18.4	6.0	0.4	1.2	0.0	0.0	0.4	0.0
TOTAL	100.0	2.0	11.2	0.4	0.0	57.2	10.0	0.8	4.0	0.0	0.0	0.8	0.0

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	LOOSE HOSE	HOSE RUPTR	WELD/ GASKT FAIL	2ND WG FAIL	1ST PIPE RUPTR	2ND PIPE RUPTR	1ST TANK RUPTR	2ND TANK RUPTR	1ST PIPE CORR	2ND PIPE CORR	1ST TANK CORR	2ND TANK CORR	OTHER EVENTS
1	2.8	1.2	0.0	0.0	0.8	0.0	0.4	0.0	0.8	0.0	0.4	0.0	0.0
2- 5	16.8	4.4	11.6	0.0	2.4	0.0	1.6	0.0	3.2	0.0	8.8	0.4	0.0
6-10	13.6	5.6	15.6	0.4	2.0	0.4	2.4	0.0	3.6	0.0	27.2	0.8	2.4
11-15	15.2	8.4	16.4	4.0	2.8	0.0	2.0	0.0	0.8	0.0	24.0	5.2	2.8
16-20	14.8	2.4	11.6	3.2	1.6	0.0	2.8	0.0	1.6	0.4	15.2	6.8	6.4
TOTAL	63.2	22.0	55.2	7.6	9.6	0.4	9.2	0.0	10.0	0.4	75.6	13.2	11.6

a/ Frequencies are expressed as percent of iterations in which the specified event occurred.

EXHIBIT B-4

FAILURE FREQUENCIES FOR EXISTING TANK RETROFIT WITH CORROSION PROTECTION a/

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	1ST FAIL	CATAS-TROPH RLS	1ST PIPE REPL	2ND PIPE REPL	3RD PIPE REPL	1ST TANK REPL	2ND TANK REPL	3RD TANK REPL	1ST OVER FLOW	2ND OVER FLOW	TANK INSTAL DEFIC	PIPE INSTAL DEFIC	WELD GASKET INSTAL
1	37.6	0.0	0.4	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.8	0.4
2- 5	26.1	0.4	0.4	0.0	0.0	8.9	1.2	0.0	1.2	0.0	0.4	0.0	0.0
6-10	19.4	1.3	1.7	0.0	0.0	3.8	0.0	0.0	1.3	0.4	0.0	0.0	0.0
11-15	9.7	0.4	1.2	0.0	0.0	5.9	0.8	0.0	2.0	0.0	0.0	0.0	0.0
16-20	7.1	0.0	0.4	0.0	0.0	6.3	0.4	0.0	1.2	0.0	0.0	0.0	0.0
TOTAL	99.9	2.1	4.1	0.0	0.0	28.7	2.4	0.0	5.7	0.4	0.4	0.8	0.4

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	LOOSE HOSE	HOSE RUPTR	WELD/ GASKT FAIL	2ND WG FAIL	1ST PIPE RUPTR	2ND PIPE RUPTR	1ST TANK RUPTR	2ND TANK RUPTR	1ST PIPE CORR	2ND PIPE CORR	1ST TANK CORR	2ND TANK CORR	OTHER EVENTS
1	3.0	0.0	16.0	0.0	4.6	0.0	0.4	0.0	3.8	0.0	11.8	0.0	0.0
2- 5	14.5	6.4	13.6	0.8	1.6	0.0	2.9	0.0	0.0	0.0	1.6	0.0	0.0
6-10	15.5	6.0	14.0	0.8	1.6	0.4	0.8	0.0	0.8	0.0	1.6	0.0	0.8
11-15	9.7	6.3	8.5	1.2	2.8	0.4	2.9	0.4	0.0	0.0	2.0	0.4	0.8
16-20	10.5	6.3	9.7	1.7	2.4	0.0	3.7	0.0	0.4	0.0	4.1	0.0	3.3
TOTAL	53.2	25.0	61.8	4.5	13.0	0.8	10.7	0.4	5.0	0.0	21.1	0.4	4.9

a/ Frequencies are expressed as percent of iterations in which the specified event occurred.

EXHIBIT B-5

FAILURE FREQUENCIES FOR EXISTING TANK RETROFIT WITH CORROSION PROTECTION AND LEAK TESTED SEMI-ANNUALLY a/

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	1ST FAIL	CATAS-TROPH RLS	1ST PIPE REPL	2ND PIPE REPL	3RD PIPE REPL	1ST TANK REPL	2ND TANK REPL	3RD TANK REPL	1ST OVER FLOW	2ND OVER FLOW	TANK INSTAL DEFIC	PIPE INSTAL DEFIC	WELD GASKET INSTAL
1	37.8	0.0	7.1	0.4	0.0	11.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2- 5	26.1	0.4	2.0	1.2	0.0	5.1	0.8	0.0	1.2	0.0	0.0	0.0	0.0
6-10	19.3	1.3	3.3	0.8	0.0	3.8	0.0	0.0	1.3	0.4	0.0	0.0	0.0
11-15	9.7	0.4	3.4	0.8	0.0	4.2	1.2	0.0	2.0	0.0	0.0	0.0	0.0
16-20	7.1	0.0	2.4	0.0	0.0	8.4	0.0	0.0	1.2	0.0	0.0	0.0	0.0
TOTAL	100.0	2.1	18.2	3.2	0.0	32.8	2.0	0.0	5.7	0.4	0.0	0.0	0.0

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	LOOSE HOSE	HOSE RUPTR	WELD/ GASKT FAIL	2ND WG FAIL	1ST PIPE RUPTR	2ND PIPE RUPTR	1ST TANK RUPTR	2ND TANK RUPTR	1ST PIPE CORR	2ND PIPE CORR	1ST TANK CORR	2ND TANK CORR	OTHER EVENTS
1	2.9	0.0	16.0	0.0	4.6	0.0	0.4	0.0	3.8	0.0	12.2	0.0	0.0
2- 5	14.7	6.4	13.1	5.4	1.6	0.0	2.9	0.0	0.0	0.8	1.6	0.0	1.7
6-10	13.8	6.0	13.8	5.5	1.6	0.4	0.8	0.0	0.8	0.0	1.6	0.0	2.9
11-15	9.6	6.3	8.0	7.1	2.8	0.4	2.4	0.4	0.0	0.0	2.0	0.0	3.3
16-20	9.7	6.3	9.7	5.4	2.4	0.0	3.8	0.0	0.4	0.0	4.1	0.0	3.3
TOTAL	50.7	25.0	60.6	23.4	13.0	0.8	10.3	0.4	5.0	0.8	21.5	0.0	11.2

a/ Frequencies are expressed as percent of iterations in which the specified event occurred.

EXHIBIT B-6

FAILURE FREQUENCIES FOR EXISTING TANK REPLACED WITH NEW TANK EQUIPPED WITH FULL SECONDARY CONTAINMENT a/

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	1ST FAIL	CATAS-TROPH RLS	1ST PIPE REPL	2ND PIPE REPL	3RD PIPE REPL	1ST TANK REPL	2ND TANK REPL	3RD TANK REPL	1ST OVER FLOW	2ND OVER FLOW	TANK INSTAL DEFIC	PIPE INSTAL DEFIC	WELD GASKET INSTAL
1	15.6	0.0	3.6	0.0	0.0	3.6	0.0	0.0	0.0	0.0	2.8	2.0	0.4
2- 5	36.8	0.4	6.8	2.4	2.0	8.0	1.6	0.4	0.8	0.0	0.0	0.0	0.0
6-10	30.0	0.4	5.6	4.8	2.0	24.0	6.0	1.2	1.6	0.0	0.0	0.0	0.0
11-15	12.4	0.8	8.0	1.2	2.4	19.2	10.0	6.0	2.0	0.0	0.0	0.0	0.0
16-20	5.2	0.4	6.4	2.0	1.6	17.2	13.6	4.8	0.4	0.0	0.0	0.0	0.0
TOTAL	100.0	2.0	30.4	10.4	8.0	72.0	31.2	12.4	4.8	0.0	2.8	2.0	0.4

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	LOOSE HOSE	HOSE RUPTR	WELD/ GASKT FAIL	2ND WG FAIL	1ST PIPE RUPTR	2ND PIPE RUPTR	1ST TANK RUPTR	2ND TANK RUPTR	1ST PIPE CORR	2ND PIPE CORR	1ST TANK CORR	2ND TANK CORR	OTHER EVENTS
1	5.6	1.6	0.0	0.0	0.0	0.0	0.4	0.0	1.6	0.0	0.4	0.0	0.0
2- 5	14.8	5.2	11.6	0.0	1.6	0.0	2.8	0.0	5.2	2.4	6.0	0.8	2.0
6-10	13.6	6.8	15.6	0.0	3.6	0.0	6.0	0.0	2.4	4.0	19.6	5.2	3.2
11-15	9.2	6.4	16.4	0.4	7.2	0.0	2.8	0.0	0.4	0.8	19.2	10.4	10.8
16-20	11.2	6.8	12.8	0.8	7.6	0.8	2.4	0.4	0.4	1.6	18.0	9.2	8.4
TOTAL	54.4	26.8	56.4	1.2	20.0	0.8	14.4	0.4	10.0	8.8	63.2	25.6	24.4

a/ Frequencies are expressed as percent of iterations in which the specified event occurred.

EXHIBIT B-7

FAILURE FREQUENCIES FOR EXISTING TANK REPLACED WITH NEW TANK EQUIPPED WITH FULL SECONDARY CONTAINMENT AND CORROSION PROTECTION a/

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	1ST FAIL	CATAS-TROPH RLS	1ST PIPE REPL	2ND PIPE REPL	3RD PIPE REPL	1ST TANK REPL	2ND TANK REPL	3RD TANK REPL	1ST OVER FLOW	2ND OVER FLOW	TANK INSTAL DEFIC	PIPE INSTAL DEFIC	WELD GASKET INSTAL
1	17.2	0.0	2.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	2.8	2.0	0.4
2- 5	32.4	0.4	2.0	0.0	0.0	2.0	0.4	0.0	0.8	0.0	0.0	0.0	0.0
6-10	26.0	0.4	4.0	0.0	0.0	7.2	0.0	0.0	1.6	0.0	0.0	0.0	0.0
11-15	15.2	0.8	8.0	0.4	0.0	3.2	0.8	0.0	2.0	0.0	0.0	0.0	0.0
16-20	9.2	0.4	6.4	1.2	0.0	1.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0
TOTAL	100.0	2.0	22.4	1.6	0.0	16.8	1.2	0.4	4.4	0.0	2.8	2.0	0.4

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	LOOSE HOSE	HOSE RUPTR	WELD/ GASKT FAIL	2ND WG FAIL	1ST PIPE RUPTR	2ND PIPE RUPTR	1ST TANK RUPTR	2ND TANK RUPTR	1ST PIPE CORR	2ND PIPE CORR	1ST TANK CORR	2ND TANK CORR	OTHER EVENTS
1	5.2	1.6	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
2- 5	16.4	5.2	14.4	0.0	1.6	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
6-10	10.4	6.8	16.4	0.4	3.6	0.0	6.8	0.0	0.0	0.0	0.0	0.0	0.0
11-15	10.0	6.4	14.4	0.4	7.2	0.0	3.2	0.0	0.4	0.0	0.0	0.0	4.8
16-20	10.0	6.8	12.4	0.4	7.6	0.8	0.8	0.0	0.0	0.0	0.4	0.0	2.8
TOTAL	52.0	26.8	57.6	1.2	20.0	0.8	13.2	0.0	0.4	0.0	0.4	0.0	7.6

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a/ Frequencies are expressed as percent of iterations in which the specified event occurred.

EXHIBIT B-8

FAILURE FREQUENCIES FOR EXISTING TANK LEAK TESTED SEMI-ANNUALLY a/

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	1ST FAIL	CATAS-TROPH RLS	1ST PIPE REPL	2ND PIPE REPL	3RD PIPE REPL	1ST TANK REPL	2ND TANK REPL	3RD TANK REPL	1ST OVER FLOW	2ND OVER FLOW	TANK INSTAL DEFIC	PIPE INSTAL DEFIC	WELD GASKET INSTAL
1	43.5	0.0	8.8	0.0	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2- 5	36.8	0.4	4.6	2.5	0.0	25.5	1.2	0.0	1.2	0.0	0.0	0.0	0.0
6-10	15.0	1.3	2.5	0.8	0.4	26.2	8.8	0.4	1.3	0.4	0.4	0.0	0.0
11-15	4.1	0.4	6.7	0.4	0.0	14.7	13.4	2.0	1.2	0.0	0.0	0.0	0.0
16-20	0.4	0.0	5.4	0.8	0.0	7.9	21.7	6.8	1.2	0.0	0.0	0.0	0.0
TOTAL	99.8	2.1	28.0	4.5	0.4	88.5	45.1	9.2	4.9	0.4	0.4	0.0	0.0

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	LOOSE HOSE	HOSE RUPTR	WELD/ GASKT FAIL	2ND WG FAIL	1ST PIPE RUPTR	2ND PIPE RUPTR	1ST TANK RUPTR	2ND TANK RUPTR	1ST PIPE CORR	2ND PIPE CORR	1ST TANK CORR	2ND TANK CORR	OTHER EVENTS
1	4.2	0.0	22.6	0.0	4.6	0.0	0.0	0.0	5.4	0.0	16.7	0.0	0.0
2- 5	15.0	6.4	13.0	6.7	2.0	0.0	2.5	0.0	1.6	2.1	27.3	0.8	2.5
6-10	15.1	5.9	8.4	11.3	1.2	0.4	2.0	0.4	0.0	0.0	25.2	7.6	5.4
11-15	12.6	6.3	9.7	7.5	2.8	0.4	2.8	0.0	3.3	0.0	13.3	11.7	6.7
16-20	10.1	6.3	6.9	8.0	2.4	0.0	3.8	0.0	3.3	0.4	5.0	21.3	8.8
TOTAL	57.0	24.9	60.6	33.5	13.0	0.8	11.1	0.4	13.6	2.5	87.5	41.4	23.4

a/ Frequencies are expressed as percent of iterations in which the specified event occurred.

EXHIBIT B-9

FAILURE FREQUENCIES FOR EXISTING TANK RETROFIT WITH EXCAVATION ZONE MONITORING a/

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	1ST FAIL	CATAS-TROPH RLS	1ST PIPE REPL	2ND PIPE REPL	3RD PIPE REPL	1ST TANK REPL	2ND TANK REPL	3RD TANK REPL	1ST OVER FLOW	2ND OVER FLOW	TANK INSTAL DEFIC	PIPE INSTAL DEFIC	WELD GASKET INSTAL
1	43.7	0.0	4.6	0.0	0.0	16.8	0.0	0.0	0.4	0.0	0.0	0.8	0.4
2- 5	36.5	0.4	5.0	0.0	0.0	29.5	1.6	0.0	1.6	0.0	0.0	0.0	0.0
6-10	15.5	1.3	4.7	0.8	0.0	26.5	11.8	0.4	0.8	0.0	0.4	0.0	0.0
11-15	3.7	0.4	5.5	0.4	0.0	12.5	19.7	4.6	1.6	0.0	0.4	0.0	0.0
16-20	0.4	0.0	2.8	0.0	0.0	5.0	19.6	8.5	0.8	0.0	0.4	0.0	0.0
TOTAL	99.8	2.1	22.6	1.2	0.0	90.3	52.7	13.5	5.2	0.0	1.2	0.8	0.4

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	LOOSE HOSE	HOSE RUPTR	WELD/ GASKT FAIL	2ND WG FAIL	1ST PIPE RUPTR	2ND PIPE RUPTR	1ST TANK RUPTR	2ND TANK RUPTR	1ST PIPE CORR	2ND PIPE CORR	1ST TANK CORR	2ND TANK CORR	OTHER EVENTS
1	4.2	0.0	21.4	0.0	4.6	0.0	0.0	0.0	5.5	0.0	16.8	0.0	0.0
2- 5	14.7	6.4	14.7	11.4	2.0	0.0	2.0	0.0	1.6	0.0	26.9	1.6	0.4
6-10	13.8	5.9	9.2	10.5	1.2	0.4	2.4	0.4	0.0	0.0	24.7	8.9	5.0
11-15	12.2	6.3	9.7	8.9	2.8	0.4	2.8	0.0	3.3	0.4	13.4	16.8	12.2
16-20	9.7	6.3	6.4	12.5	2.4	0.0	5.0	0.0	3.3	0.0	4.2	16.4	12.2
TOTAL	54.6	24.9	61.4	43.3	13.0	0.8	12.2	0.4	13.7	0.4	86.0	43.7	29.8

a/ Frequencies are expressed as percent of iterations in which the specified event occurred.

EXHIBIT B-10

FAILURE FREQUENCIES FOR EXISTING TANK RETROFIT WITH CORROSION PROTECTION AND EXCAVATION ZONE MONITORING a/

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	1ST FAIL	CATAS-TROPH RLS	1ST PIPE REPL	2ND PIPE REPL	3RD PIPE REPL	1ST TANK REPL	2ND TANK REPL	3RD TANK REPL	1ST OVER FLOW	2ND OVER FLOW	TANK INSTAL DEFIC	PIPE INSTAL DEFIC	WELD GASKET INSTAL
1	38.0	0.0	3.8	0.0	0.0	12.2	0.0	0.0	0.4	0.0	0.0	0.8	0.4
2- 5	26.2	0.4	2.0	0.0	0.0	4.2	1.2	0.0	1.2	0.0	0.4	0.0	0.0
6-10	19.5	1.3	3.4	0.4	0.0	3.7	0.0	0.0	0.8	0.0	0.0	0.0	0.0
11-15	9.3	0.4	2.0	0.4	0.0	4.1	1.2	0.0	1.6	0.0	0.0	0.0	0.0
16-20	7.1	0.0	2.1	0.8	0.0	7.2	0.4	0.0	1.2	0.0	0.0	0.0	0.4
TOTAL	100.1	2.1	13.3	1.6	0.0	31.4	2.8	0.0	5.2	0.0	0.4	0.8	0.8

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	LOOSE HOSE	HOSE RUPTR	WELD/ GASKT FAIL	2ND WG FAIL	1ST PIPE RUPTR	2ND PIPE RUPTR	1ST TANK RUPTR	2ND TANK RUPTR	1ST PIPE CORR	2ND PIPE CORR	1ST TANK CORR	2ND TANK CORR	OTHER EVENTS
1	3.0	0.0	16.0	0.0	4.6	0.0	0.4	0.0	3.8	0.0	11.8	0.0	0.0
2- 5	14.0	6.4	13.2	4.9	1.6	0.0	2.9	0.0	0.0	0.4	1.6	0.0	0.4
6-10	15.1	6.0	14.0	3.3	1.6	0.4	0.8	0.0	0.8	0.0	1.6	0.0	1.6
11-15	9.7	6.3	9.0	7.5	2.8	0.4	2.5	0.4	0.0	0.0	2.0	0.0	2.0
16-20	10.6	6.3	9.7	5.0	2.4	0.0	2.9	0.0	0.4	0.4	4.1	0.4	4.6
TOTAL	52.4	25.0	61.9	20.7	13.0	0.8	9.5	0.4	5.0	0.8	21.1	0.4	8.6

a/ Frequencies are expressed as percent of iterations in which the specified event occurred.

EXHIBIT B-11

FAILURE FREQUENCIES FOR EXISTING TANK REPLACED WITH NEW TANK EQUIPPED WITH EXCAVATION ZONE MONITORING a/

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	1ST FAIL	CATAS-TROPH RLS	1ST PIPE REPL	2ND PIPE REPL	3RD PIPE REPL	1ST TANK REPL	2ND TANK REPL	3RD TANK REPL	1ST OVER FLOW	2ND OVER FLOW	TANK INSTAL DEFIC	PIPE INSTAL DEFIC	WELD GASKET INSTAL
1	7.2	0.0	0.8	0.0	0.0	0.8	0.0	0.0	0.8	0.0	0.0	0.4	0.0
2- 5	40.8	0.4	1.6	0.0	0.0	10.0	0.8	0.0	1.6	0.0	0.0	0.0	0.0
6-10	30.4	0.4	6.0	0.0	0.0	29.6	2.8	0.0	2.8	0.0	0.0	0.0	0.0
11-15	14.4	0.8	4.8	0.4	0.0	23.2	8.0	1.2	2.8	0.0	0.4	0.0	0.0
16-20	7.2	0.4	4.4	1.2	0.0	15.6	18.0	6.0	2.4	0.0	0.0	0.4	0.0
TOTAL	100.0	2.0	17.6	1.6	0.0	79.2	29.6	7.2	10.4	0.0	0.4	0.8	0.0

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	LOOSE HOSE	HOSE RUPTR	WELD/ GASKT FAIL	2ND WG FAIL	1ST PIPE RUPTR	2ND PIPE RUPTR	1ST TANK RUPTR	2ND TANK RUPTR	1ST PIPE CORR	2ND PIPE CORR	1ST TANK CORR	2ND TANK CORR	OTHER EVENTS
1	2.8	1.2	0.0	0.0	0.8	0.0	0.4	0.0	0.8	0.0	0.4	0.0	0.0
2- 5	16.8	4.4	11.6	0.0	2.4	0.0	1.6	0.0	3.2	0.0	8.8	0.0	0.0
6-10	14.0	5.6	15.6	5.2	2.0	0.4	2.0	0.0	3.6	0.0	27.6	2.4	2.8
11-15	15.6	8.4	15.6	8.4	2.8	0.0	1.2	0.0	1.2	0.0	23.2	6.4	5.2
16-20	12.8	2.4	11.6	13.2	1.6	0.0	2.8	0.0	1.6	1.2	16.8	14.4	13.2
TOTAL	62.0	22.0	54.4	26.8	9.6	0.4	8.0	0.0	10.4	1.2	76.8	23.2	21.2

a/ Frequencies are expressed as percent of iterations in which the specified event occurred.

EXHIBIT B-12

FAILURE FREQUENCIES FOR EXISTING TANK REPLACED WITH NEW TANK EQUIPPED WITH CORROSION PROTECTION AND EXCAVATION ZONE MONITORING a/

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	1ST FAIL	CATAS- TROPH RLS	1ST PIPE REPL	2ND PIPE REPL	3RD PIPE REPL	1ST TANK REPL	2ND TANK REPL	3RD TANK REPL	1ST OVER FLOW	2ND OVER FLOW	TANK INSTAL DEFIC	PIPE INSTAL DEFIC	WELD GASKET INSTAL
1	7.2	0.0	0.8	0.0	0.0	0.8	0.0	0.0	0.8	0.0	0.0	0.4	0.0
2- 5	41.2	0.4	1.6	0.0	0.0	10.0	0.8	0.0	1.6	0.0	0.0	0.0	0.0
6-10	30.0	0.4	6.4	0.0	0.0	29.6	2.8	0.0	2.8	0.0	0.0	0.0	0.0
11-15	14.4	0.8	4.8	0.4	0.0	23.2	8.0	1.2	2.8	0.0	0.4	0.0	0.0
16-20	7.2	0.4	4.4	1.2	0.0	15.6	18.0	6.0	2.4	0.0	0.0	0.4	0.0
TOTAL	100.0	2.0	18.0	1.6	0.0	79.2	29.6	7.2	10.4	0.0	0.4	0.8	0.0

YEAR(S) OF OCCURRENCE	EVENT CATEGORY												
	LOOSE HOSE	HOSE RUPTR	WELD/ GASKT FAIL	2ND WG FAIL	1ST PIPE RUPTR	2ND PIPE RUPTR	1ST TANK RUPTR	2ND TANK RUPTR	1ST PIPE CORR	2ND PIPE CORR	1ST TANK CORR	2ND TANK CORR	OTHER EVENTS
1	2.8	1.2	0.0	0.0	0.8	0.0	0.4	0.0	0.8	0.0	0.4	0.0	0.0
2- 5	16.8	4.4	11.6	0.0	2.4	0.0	1.6	0.0	3.6	0.0	8.8	0.0	0.0
6-10	14.0	5.6	15.2	5.2	2.0	0.4	2.0	0.0	3.6	0.0	27.6	2.4	2.8
11-15	15.6	8.4	15.6	8.0	2.8	0.0	1.2	0.0	1.2	0.0	23.2	6.4	5.2
16-20	12.8	2.4	11.6	13.2	1.6	0.0	2.8	0.0	1.6	1.2	16.8	14.4	13.2
TOTAL	62.0	22.0	54.0	26.4	9.6	0.4	8.0	0.0	10.8	1.2	76.8	23.2	21.2

a/ Frequencies are expressed as percent of iterations in which the specified event occurred.

Corrosion protection, obviously, affects the frequency of corrosion failure events. According to the HWTF model results, corrosion protection alone, that is, not combined with any other protective measures, reduces the frequency of tank corrosion from 86.9 percent to 21.1 percent and the frequency of pipe corrosion from 15.0 percent to 5.0 percent compared to an existing tank system under the baseline scenario (see Exhibits B-2 and B-4). Thus, it appears that corrosion protection is an effective means of achieving substantial reductions in the frequency of corrosion events.

Double-walled tanks and pipes appear to affect the frequencies of two types of failure events: (1) rupture events and (2) corrosion events. The increased frequency of rupture events for double-walled tanks and pipes is partially explained by the fact that the reported frequency represents a rupture of either wall of the tank or pipe. For a double-walled tank, the inner wall, because it is subject to fewer stresses than the outer wall, was assumed to be 50 percent as likely to rupture, while the outer wall was assumed to be as likely to rupture as the wall of a single-walled tank. The frequency tables show that a new double-walled tank is about 1.5 times as likely to rupture as a new single-walled tank, which is what one would expect given the model assumptions and the method of reporting ruptures (see Exhibits B-3 and B-6).

The failure frequency data indicate that double-walled pipes are twice as likely to rupture as single-walled pipes. In the case of pipes, the HWTF model assumes that both pipe walls have equal probability of rupturing, this probability being the same as that for a single-walled pipe. Thus, the model output is consistent with the assumptions.

The observed frequency of first tank corrosion and first pipe corrosion is about 10 percent less for double-walled systems than for single-walled systems (see Exhibits B-3 and B-6). Like ruptures, the frequencies of corrosion events also represent corrosion failures of either wall of the tank or pipe. For the outer wall of double-walled tanks and pipes, only the exterior surface was assumed to be subject to corrosion, while only the interior surface of the inner wall was assumed to be subject to corrosion. Because corrosion acts on only one surface of each wall, the frequencies of corrosion failures over a 20-year period are somewhat less for double-walled tanks and pipes. On the other hand, the frequencies of second tank and pipe leaks are larger for the double-walled system. This increase is due to a much faster replacement rate for leaking double-walled tanks (because leaks are detected very quickly), which allows the replaced tanks time to develop new leaks, unlike tanks under baseline conditions, which may continue to leak for long periods of time before replacement.

In terms of frequency of occurrence, three failure events dominate the results: (1) loose hose connections; (2) weld or gasket failures (only gaskets are modeled for an underground, carbon steel tank); and (3) tank corrosion. For all scenarios, 50 to 60 percent of iterations have loose hose connections and gasket failures. For scenarios that incorporate no measures to prevent corrosion, between 75 and 85 percent of the iterations have tank corrosion failures. On the other hand, for scenarios that do incorporate measures to prevent corrosion, the frequency of corrosion events is much smaller. For existing tanks retrofit with corrosion protection and for new double-walled tanks with corrosion protection the frequency of corrosion failures are 21 and 0.4 percent, respectively.

For the scenario of an existing tank replaced with a new tank equipped with corrosion protection and excavation zone monitoring (Exhibit B-12), the frequencies of corrosion events are the same as those for an existing tank replaced with a new tank equipped with only excavation zone monitoring (Exhibit B-11). The corrosion failure frequencies for this scenario should have been substantially smaller than the corrosion failure frequencies for the scenario with only excavation zone monitoring. Pope-Reid Associates, Inc., is currently investigating these results. Although the release volumes for this tank with corrosion are likely to be too high, we anticipate that revised release volumes would not result in significant changes among the relative rankings of the scenarios as presented in the next section.

B.3.2 Release Volumes

Analysis of the release volume results of the HWTF model is one means of evaluating the performance of a tank system under different regulatory scenarios. Although the model generated approximately 238 20-year release profiles for each scenario, we have summarized these results for each scenario instead of presenting all release profiles.

Rather than estimating risks for all iterations produced by the HWTF model, we have used a statistical technique known as cluster analysis.[3] Thus, risk estimates for each scenario are based on six representative release profiles rather than 238. These representative release profiles are shown in Exhibits B-13 through B-23. To rank regulatory scenarios based on release volumes, therefore, we calculated the weighted average total volume released for each scenario (i.e., we summed the total volumes released for each of the six representative release profiles and multipled each by its frequency of occurrence). We then summed these values to obtain a weighted average release profile for each scenario. Based on these averages, we ranked the scenarios from highest to lowest total weighted average volume released over the 20-year time horizon, in descending order of volume reduction from baseline, as follows:

- Existing tank replaced with new tank equipped with full secondary containment and corrosion protection;
- Existing tank retrofit with excavation zone monitoring and corrosion protection;
- Existing tank retrofit with excavation zone monitoring;

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[3] For a detailed description of the cluster analysis procedure, see Section 4.5 of this report.

EXHIBIT B-13

REPRESENTATIVE RELEASE PROFILES FOR EXISTING TANK REGULATED UNDER BASELINE

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.366	1.140	2.904	0.005	0.005	4.054
2	.218	0.225	5.180	46.160	11.000	62.565
3	.206	0.256	0.280	4.816	37.230	42.582
4	.181	16.510	16.420	0.000	0.002	32.932
5	.021	19.420	31.600	43.970	50.360	145.350
6	.008	0.000	0.000	0.000	0.000	0.000
WEIGHTED AVERAGE	1.000	3.915	5.885	11.980	11.127	32.908

EXHIBIT B-14

REPRESENTATIVE RELEASE PROFILES FOR NEW TANK REGULATED UNDER BASELINE

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.360	0.000	0.012	0.000	1.170	1.182
2	.300	0.000	0.001	4.483	35.850	40.334
3	.164	0.001	20.602	18.270	0.000	38.873
4	.156	1.332	0.378	27.563	20.580	49.853
5	.012	10.930	30.800	43.700	55.500	140.930
6	.008	0.000	0.000	0.000	0.000	0.000
WEIGHTED AVERAGE	1.000	0.339	3.812	9.165	15.053	28.369

EXHIBIT B-15

REPRESENTATIVE RELEASE PROFILES FOR EXISTING TANK RETROFIT WITH CORROSION PROTECTION

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.806	0.000	1.090	0.738	0.367	2.195
2	.068	24.900	0.000	0.000	0.000	24.900
3	.055	0.000	0.000	0.000	0.000	0.000
4	.042	0.002	0.005	0.451	27.111	27.569
5	.017	20.270	30.670	43.350	56.100	150.390
6.	.013	32.140	59.020	17.020	0.000	108.180
WEIGHTED AVERAGE	1.001	2.456	2.167	1.572	2.388	8.583

EXHIBIT B-16

REPRESENTATIVE RELEASE PROFILES FOR EXISITNG TANK RETROFIT WITH CORROSION PROTECTION AND LEAK TESTED SEMI-ANNUALLY

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.874	1.260	0.000	0.000	0.868	2.128
2	.059	0.000	0.000	0.000	0.000	0.000
3	.025	0.000	0.000	0.000	5.359	5.359
4	.021	0.000	0.000	0.000	9.580	9.580
5	.013	0.122	0.000	15.100	0.000	15.222
6	.008	14.700	1.660	0.000	0.000	16.360
WEIGHTED AVERAGE	1.000	1.220	0.013	0.196	1.094	2.524

EXHIBIT B-17

REPRESENTATIVE RELEASE PROFILES FOR EXISTING TANK REPLACED WITH NEW TANK EQUIPPED WITH FULL SECONDARY CONTAINMENT

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.848	0.072	0.080	0.082	0.090	0.324
2	.116	0.000	0.000	0.000	0.000	0.000
3	.016	0.000	0.718	31.450	35.600	67.768
4	.008	0.000	0.939	42.110	11.000	54.049
5	.008	0.000	1.870	21.690	34.670	58.230
6	.004	16.300	0.003	0.005	0.005	16.313
WEIGHTED AVERAGE	1.000	0.126	0.102	1.083	1.011	2.323

EXHIBIT B-18

REPRESENTATIVE RELEASE PROFILES FOR EXISTING TANK REPLACED WITH NEW TANK EQUIPPED WITH FULL SECONDARY CONTAINMENT AND CORROSION PROTECTION

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.780	0.072	0.080	0.080	0.080	0.312
2	.116	0.000	0.000	0.000	0.000	0.000
3	.052	0.000	1.410	0.000	0.000	1.410
4	.028	0.000	0.000	0.000	2.160	2.160
5	.020	0.000	0.000	2.950	0.000	2.950
6	.004	16.300	0.000	0.002	0.005	16.307
WEIGHTED AVERAGE	1.000	0.121	0.136	0.121	0.123	0.501

EXHIBIT B-19

REPRESENTATIVE RELEASE PROFILES FOR EXISTING TANK LEAK TESTED SEMI-ANNUALLY

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.699	3.670	0.000	0.824	1.180	5.674
2	.126	0.000	5.210	0.000	0.007	5.217
3	.105	0.541	5.350	0.000	0.038	5.929
4	.054	7.340	0.000	0.000	0.000	7.340
5	.008	0.000	0.000	0.000	0.000	0.000
6.	.008	15.100	0.000	0.000	0.000	15.100
WEIGHTED AVERAGE	1.000	3.139	1.218	0.576	0.830	5.763

EXHIBIT B-20

REPRESENTATIVE RELEASE PROFILES FOR EXISTING TANK RETROFIT WTIH EXCAVATION ZONE MONITORING

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.887	0.019	1.030	0.000	0.000	1.049
2	.067	0.016	0.785	2.500	0.016	3.317
3	.017	0.004	7.583	0.000	0.000	7.587
4	.017	5.097	0.010	0.896	0.000	6.003
5	.008	0.000	0.000	0.000	0.000	0.000
6	.004	0.293	0.000	14.400	0.000	14.693
WEIGHTED AVERAGE	1.000	0.106	1.095	0.240	0.001	1.443

EXHIBIT B-21

REPRESENTATIVE RELEASE PROFILES FOR EXISTING TANK RETROFIT WITH CORROSION PROTECTION AND EXCAVATION ZONE MONITORING

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.878	0.914	0.000	0.000	0.003	0.917
2	.055	0.000	0.000	0.000	0.000	0.000
3	.025	2.621	0.904	0.307	0.000	3.832
4	.021	9.800	0.000	0.000	0.000	9.800
5	.017	5.097	0.000	0.000	0.000	5.097
6	.004	0.012	0.000	15.100	0.000	15.112
WEIGHTED AVERAGE	1.000	1.161	0.023	0.068	0.003	1.254

EXHIBIT B-22

REPRESENTATIVE RELEASE PROFILES FOR EXISTING TANK REPLACED WITH NEW TANK EQUIPPED WITH EXCAVATION ZONE MONITORING

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.952	0.248	0.400	0.412	0.400	1.460
2	.016	0.000	4.020	0.000	0.009	4.029
3	.012	1.970	0.000	0.000	7.570	9.540
4	.008	5.051	0.786	1.624	0.025	7.486
5	.008	0.000	0.502	8.730	0.000	9.232
6	.004	0.000	0.000	0.000	0.000	0.000
WEIGHTED AVERAGE	1.000	0.300	0.455	0.475	0.472	1.703

EXHIBIT B-23

REPRESENTATIVE RELEASE PROFILES FOR EXISTING TANK REPLACED WITH NEW TANK EQUIPPED WITH CORROSION PROTECTION AND EXCAVATION ZONE MONITORING

PROFILE	WEIGHT	VOLUME RELEASED (cubic meters)				
		YRS. 1- 5	YRS. 6-10	YRS. 11-15	YRS. 16-20	TOTAL
1	.952	0.248	0.400	0.412	0.400	1.460
2	.016	0.000	4.020	0.000	0.009	4.029
3	.012	1.970	0.000	0.000	7.570	9.540
4	.008	0.000	0.502	8.730	0.000	9.232
5	.008	5.051	0.786	1.624	0.025	7.486
6	.004	0.000	0.000	0.000	0.000	0.000
WEIGHTED AVERAGE	1.000	0.300	0.455	0.475	0.472	1.703

- Existing tank replaced with new tank equipped with excavation zone monitoring and corrosion protection;
- Existing tank replaced with new tank equipped with excavation zone monitoring;
- Existing tank replaced with new tank equipped with full secondary containment;
- Existing tank retrofit with corrosion protection and leak tested semi-annually;
- Existing tank leak tested semi-annually;
- Existing tank retrofit with corrosion protection; and
- New tank, baseline.

Weighted average 20-year release volumes for each scenario are shown in Exhibit B-24.

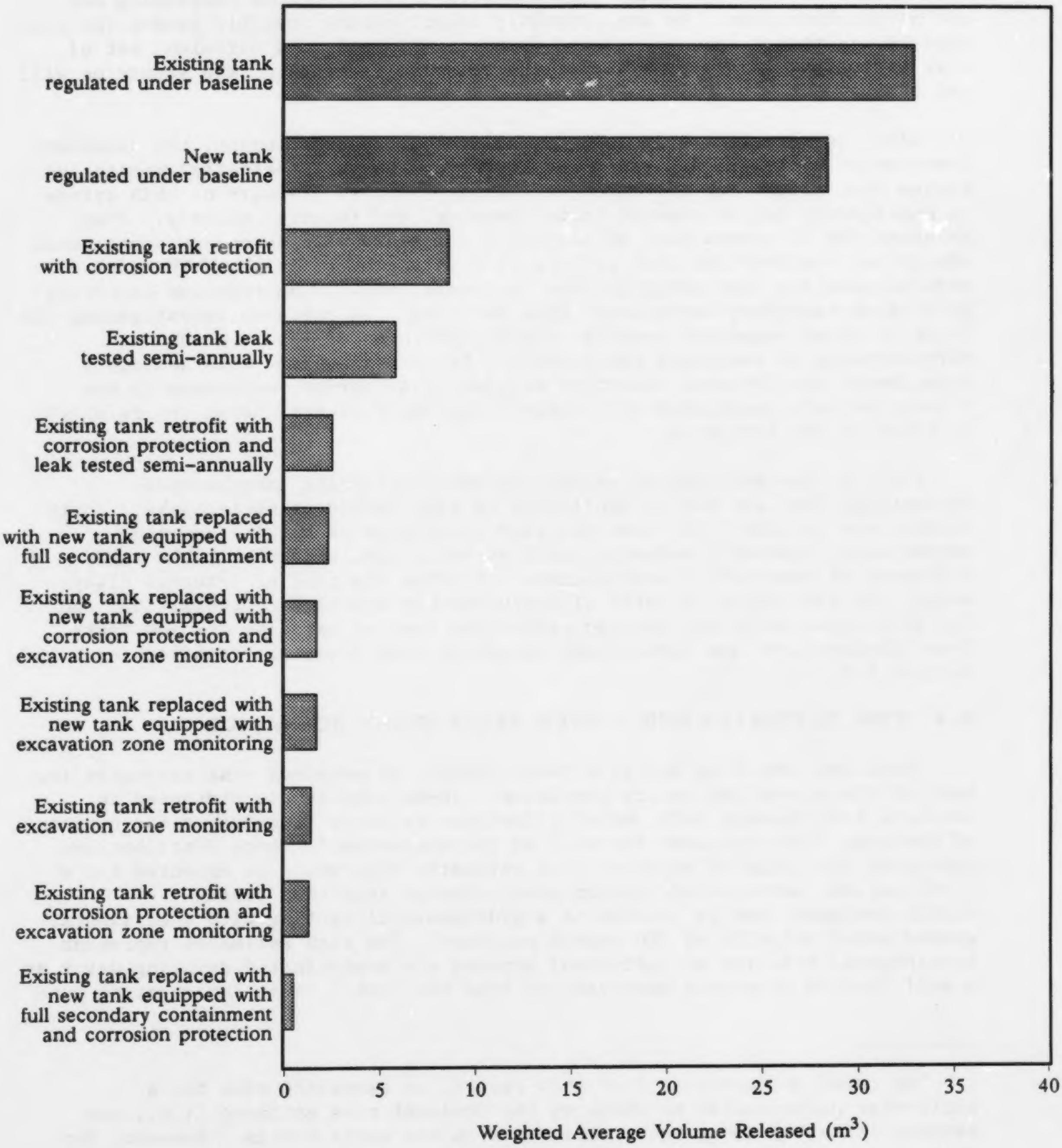
As indicated, the most effective scenario in reducing release volumes compared to baseline for the selected tank technology is the replacement of an existing tank with a new tank equipped with full secondary containment and corrosion protection. Other scenarios that were effective in reducing release volumes were existing tanks equipped with (1) excavation zone monitoring and corrosion protection; or (2) excavation zone monitoring. Also, scenarios in which existing tanks were replaced by new tanks equipped with either: (1) excavation zone monitoring; (2) excavation zone monitoring and corrosion protection; or (3) full secondary containment, also showed marked decreases in release volumes when compared to baseline.

The existing tank retrofit with corrosion protection and leak tested semi-annually performed nearly as well as the tank with full secondary containment in terms of release volume reduction; however, leak testing and corrosion protection, when employed singly, were significantly less effective than the previously-mentioned scenarios. However, these scenarios did provide substantial decreases in total release volumes when compared to the new tank, baseline regulatory scenario.

It should be noted again that the weighted average 20-year release volumes shown in Exhibit B-24 are based on the six representative release profiles selected from the original 238 HWTF model iterations using cluster analysis techniques. We chose this statistic to represent 20-year release volumes for each scenario because it is most consistent with the risk analysis methodology, in which six representative release profiles are used to generate a risk distribution for each scenario. However, average 20-year release volumes do not take into account the timing of events and, unfortunately, some information about the six representative release profiles is also lost in presenting a weighted average. Therefore, rankings of scenarios based on weighted average release volumes may be slightly different than risk rankings for the same scenarios, particularly given the small differences in weighted average release volumes noted in Exhibit B-24.

EXHIBIT B-24

RANKING OF REGULATORY SCENARIOS BASED ON WEIGHTED AVERAGE TOTAL VOLUME RELEASED DURING 20-YEAR TIME HORIZON STORAGE TANK, UNDERGROUND, CARBON STEEL, 4000 GALLONS



Also, some caveats should be noted. As indicated in Exhibit B-24, total release volumes for existing tanks retrofit with excavation zone monitoring and corrosion protection show weighted average total release volumes that are less than those for new tanks equipped with excavation zone monitoring and corrosion protection. We are currently investigating possible causes for this anomaly. Although revised release volumes will lead to a different set of risk estimates, we anticipate that the relative rankings of the scenarios will not change.

Also, in scenarios that include full secondary containment, the secondary containment system is assumed to be equipped with an interstitial monitoring system that allows for the rapid detection of leaks. Failure of this system is considered, but it assumed to be inspected and repaired monthly. Thus, releases due to events such as corrosion for tanks with secondary containment should not continue for long periods of time; however, in the HWTF Model results used for this analysis some long-term, continuing releases involving tanks with secondary containment were observed. We are also investigating the cause of these anomalous results, which tend to under-estimate the effectiveness of secondary containment. Because scenarios with secondary containment are the most effective regulatory scenarios, decreases in the release volumes associated with these scenarios will not change the relative rankings of the scenarios.

Finally, our modeling of excavation zone monitoring incorporates assumptions that may not be applicable to many hazardous waste tanks. These assumptions include: (1) that the tank excavation is backfilled with homogeneous, isotropic material, such as sand, that will permit the rapid transport of vapor-phase contaminants; (2) that the tank of interest always stores the same volatile waste of approximately the same concentration; and (3) that vapor wells are located within two feet of existing and new tanks. These assumptions, and limitations resulting from them, are detailed in Section B.5.

B.4 RISK ESTIMATES FOR ELEVEN REGULATORY SCENARIOS

Using the Tank Risk Analsyis Model (TRAM), we obtained risk estimates for each of the eleven regulatory scenarios. These results are presented in Exhibits B-25 through B-35, which illustrate relative frequency distributions of dominant risk estimates for each of the scenarios.[4] These distributions represent the range of relative risk estimates that would be expected for a 4,000 gallon, underground, carbon steel storage tank that stores dichloromethane, and is located in a hydrogeologic setting with a horizontal ground-water velocity of 100 meters per year. The risk estimates represent carcinogenic risk for an individual exposed via contaminated drinking water at a well located 60 meters downgradient from the tank. It is important to note that because we are only considering one waste stream and one hydrogeologic setting, the distributions are only based on six risk estimates (i.e., one risk estimate is determined for each of the six representative release profiles).

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[4] As noted in Section 5.3 of this report, we summarize risk for a particular waste stream by choosing the dominant risk estimate (i.e., the maximum estimate) among the constituents in the waste stream. However, for this supplementary analysis, this assumption has no effect because we are using dichloromethane, a waste stream with only one constituent.

Based on these results, we have ranked the regulatory scenarios in descending order of risk reduction from baseline (existing tank) as follows:

- Existing tank replaced with new tank equipped with full secondary containment and corrosion protection;
- Existing tank replaced with new tank equipped with full secondary containment;
- Existing tank retrofit with corrosion protection and excavation zone monitoring;
- Existing tank replaced with new tank equipped with corrosion protection and excavation zone monitoring;
- Existing tank replaced with new tank equipped with excavation zone monitoring;
- Existing tank retrofit with excavation zone monitoring;
- Existing tank retrofit with corrosion protection and leak tested semi-annually;
- Existing tank leak tested semi-annually;
- Existing tank retrofit with corrosion protection; and
- New tank, baseline.

This ranking is based on a comparison of the most frequent risk values for each scenario. For example, in comparing a new tank under baseline (Exhibit B-35) to an existing tank retrofit with excavation zone monitoring (Exhibit B-30), we see that for the new tank, baseline, most of the risks are on the order of 10^{-4}, while for the existing tank retrofit with excavation zone monitoring, risks are on the order of 10^{-6}. Thus, the existing tank retrofit with excavation zone monitoring ranks higher than the new tank under baseline when compared to the existing tank under baseline (our base case for this analysis).[5]

In viewing Exhibits B-25 through B-35, it is clear that replacing an existing tank with a new double-walled tank (i.e., full secondary containment), with or without corrosion protection, provides the most substantial reduction in risk compared to baseline. However, excavation zone monitoring, particularly when combined with corrosion protection (see Exhibit B-28) also provides for substantial reduction in risk associated with the model tank technology.

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[5] For scenarios where the comparison of the most frequent risk values did not allow us to differentiate between them, direct comparison of the entire risk distribution was used for comparison.

As illustrated in Exhibit B-32, corrosion protection combined with leak testing also reduces risk significantly compared to baseline, but this regulatory scenario is not nearly as effective as those that include full secondary containment or excavation zone monitoring. Leak testing considered by itself for an existing tank provides a slight reduction in risk over baseline, as does corrosion protection for the same situation; however, the reduction in risk for these scenarios is not substantially different from the reduction achieved by replacing an existing tank with a new unprotected and unmonitored tank.

From these results, we conclude that regulatory scenarios that combine a protective measure that reduces failure probability with a system that allows for the rapid detection of leaks are most effective in reducing the risk associated with hazardous waste tanks. The most effective combination of these alternatives is full secondary containment with corrosion protection, where: (1) the outer tank wall prevents releases from the tank from excaping to the environment; (2) corrosion protection prevents the outer wall from being breached by external corrosion; and (3) interstitial monitoring between the walls of the double-walled tank allows for rapid detection of leaks.

For highly volatile wastes, such as dichloromethane, excavation zone monitoring is a potential option for the rapid detection of leaks. When combined with a protective measure that reduces tank failures, such as corrosion protection, excavation zone monitoring can be an effective method of reducing risks associated with hazardous waste tanks. However, it is important to note that excavation zone monitoring is limited in its applicability to hazardous waste tanks, in that it is only effective for tanks storing volatile wastes and located in a specific hydrogeologic situation. Also, it is important to note that the assumptions used to model excavation zone monitoring are more representative of a new tank site than an existing tank location.[6] Consequently, our model over-estimates the effectiveness of excavation zone monitoring for existing tanks.

Leak testing and corrosion protection, when combined, offer significant risk reduction over baseline, but are not as effective as secondary containment or excavation zone monitoring. As noted in earlier chapters of this report, leak testing will fail to detect leaks below a minimum size that may nonetheless result in some risk to an exposed individual; also, the semi-annual frequency of leak testing allows for leaks to occur and continue for substantial time periods before detection. Also, corrosion protection is effective in reducing the probability of only one (albeit important) failure mechanism associated with hazardous waste tanks.

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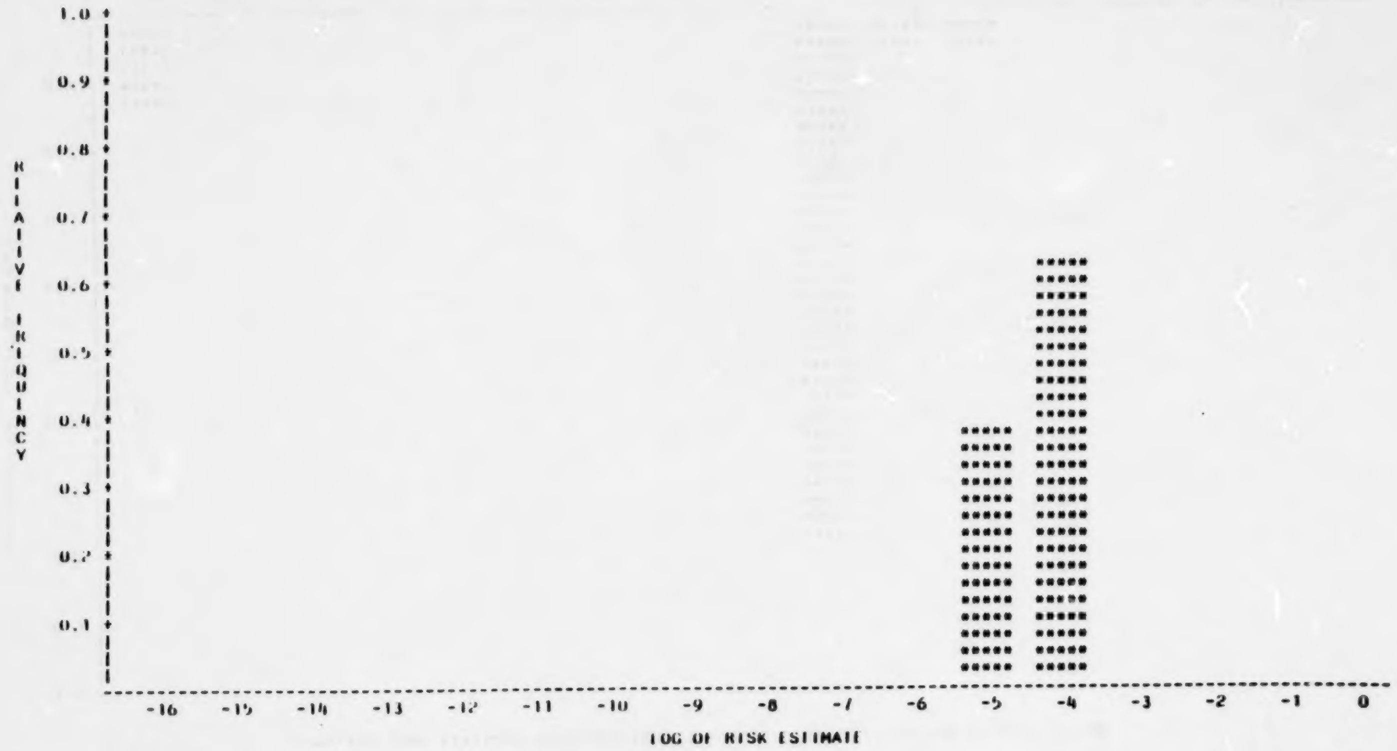
[6] See Section B.5 for a more detailed discussion of the assumptions used to model excavation zone monitoring.

EXHIBIT B-25

EXISTING TANK, BASELINE

RELATIVE FREQUENCY DISTRIBUTION OF DOMINANT RISK ESTIMATES *
STORAGE TANK, UNDERGROUND, CARBON STEEL, 4,000 GALLONS
WASTE STREAM U080, GROUND-WATER SCENARIO C
DISTANCE TO WELL 60 M

EXISTING TANK, BASELINE



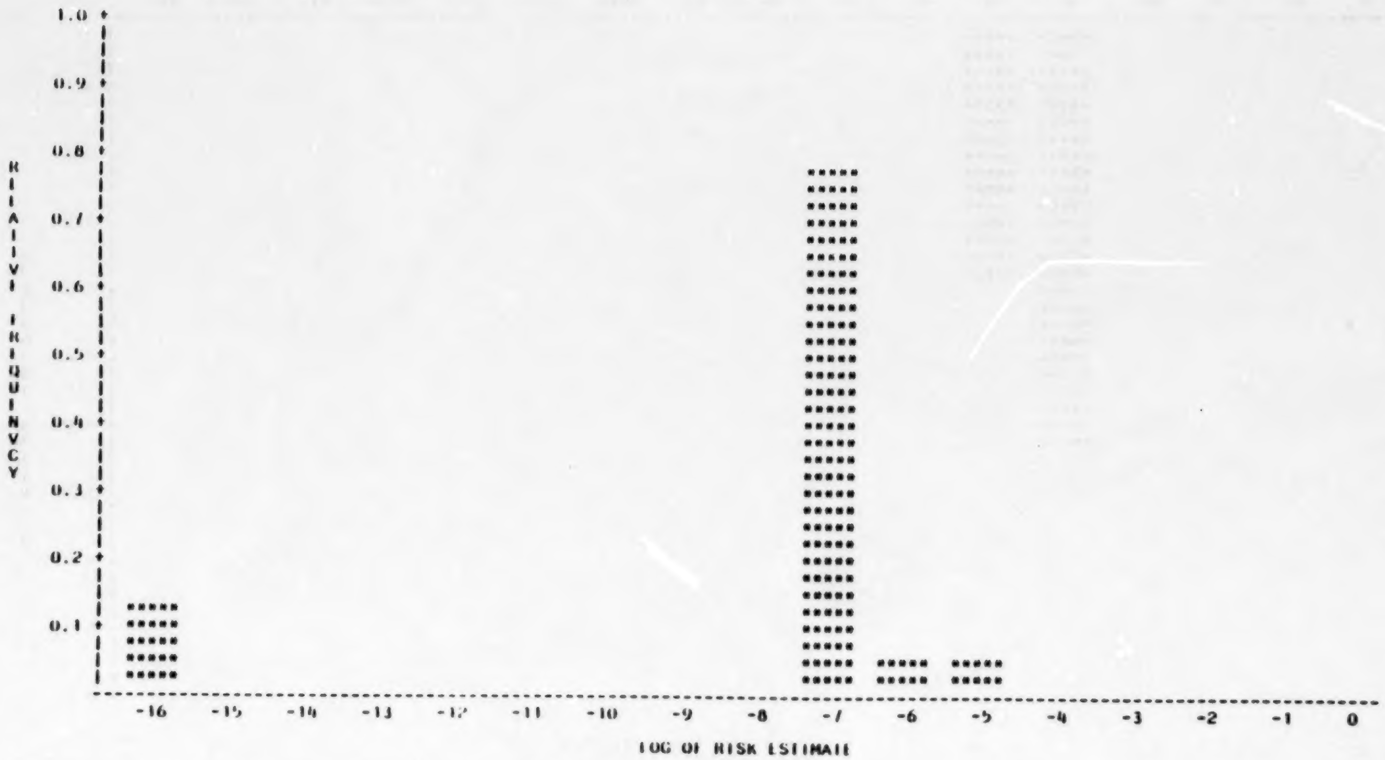
* Frequency distributions based on 6 dominant risk estimates.

EXHIBIT B-26

EXISTING TANK REPLACED WITH NEW TANK EQUIPPED WITH FULL SECONDARY CONTAINMENT AND CORROSION PROTECTION

RELATIVE FREQUENCY DISTRIBUTION OF DOMINANT RISK ESTIMATES*
STORAGE TANK, UNDERGROUND, CARBON STEEL, 4,000 GALLONS
WASTE STREAM D080, GROUND-WATER SCENARIO C
DISTANCE TO WELL 60 M

EXISTING TANK REPLACED WITH NEW DOUBLE-WALLED TANK WITH CORROSION PROTECTION



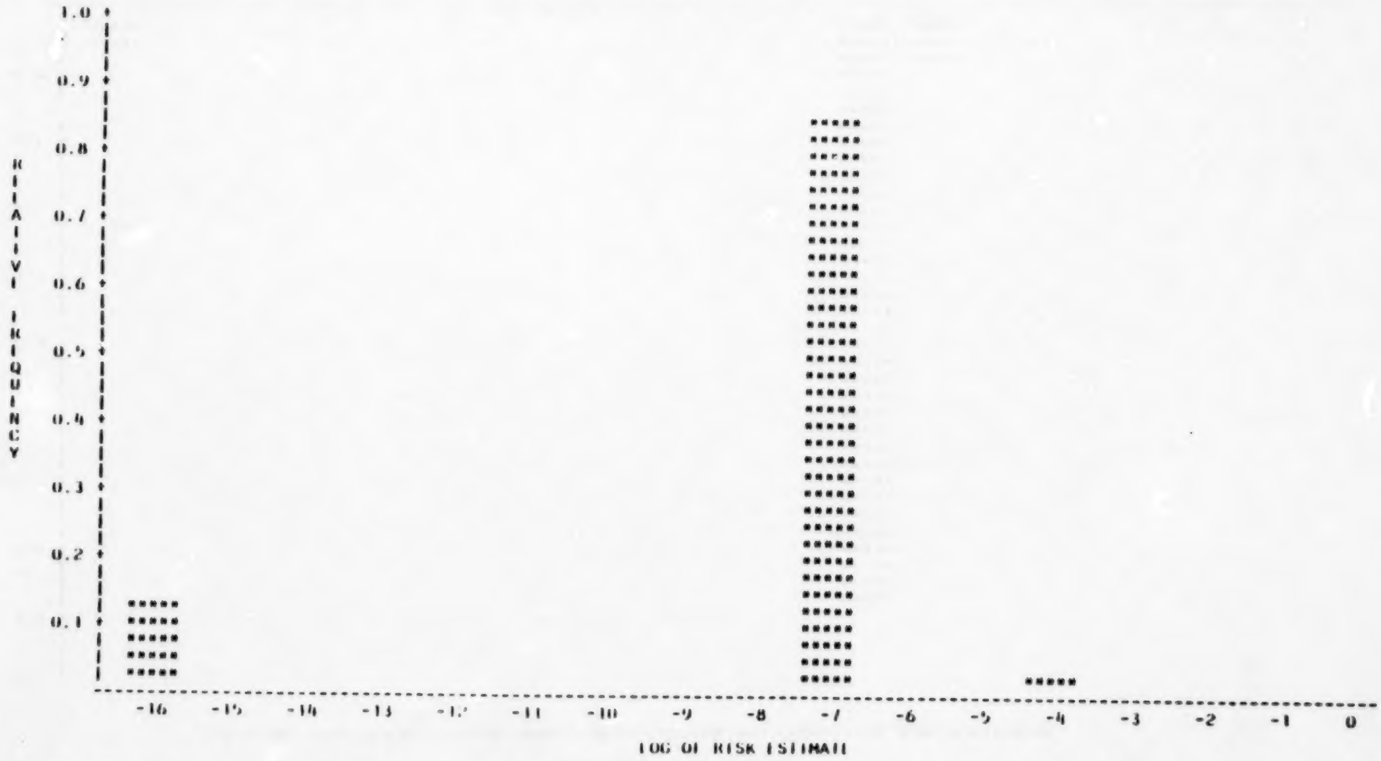
* Frequency distributions based on 6 dominant risk estimates.

EXHIBIT B-27

EXISTING TANK REPLACED WITH NEW TANK EQUIPPED WITH FULL SECONDARY CONTAINMENT

RELATIVE FREQUENCY DISTRIBUTION OF DOMINANT RISK ESTIMATES *
STORAGE TANK, UNDERGROUND, CARBON STEEL, 4,000 GALLONS
WASTE STREAM U080, GROUND-WATER SCENARIO C
DISTANCE TO WELL 60 M

EXISTING TANK REPLACED WITH NEW DOUBLE-WALLED TANK



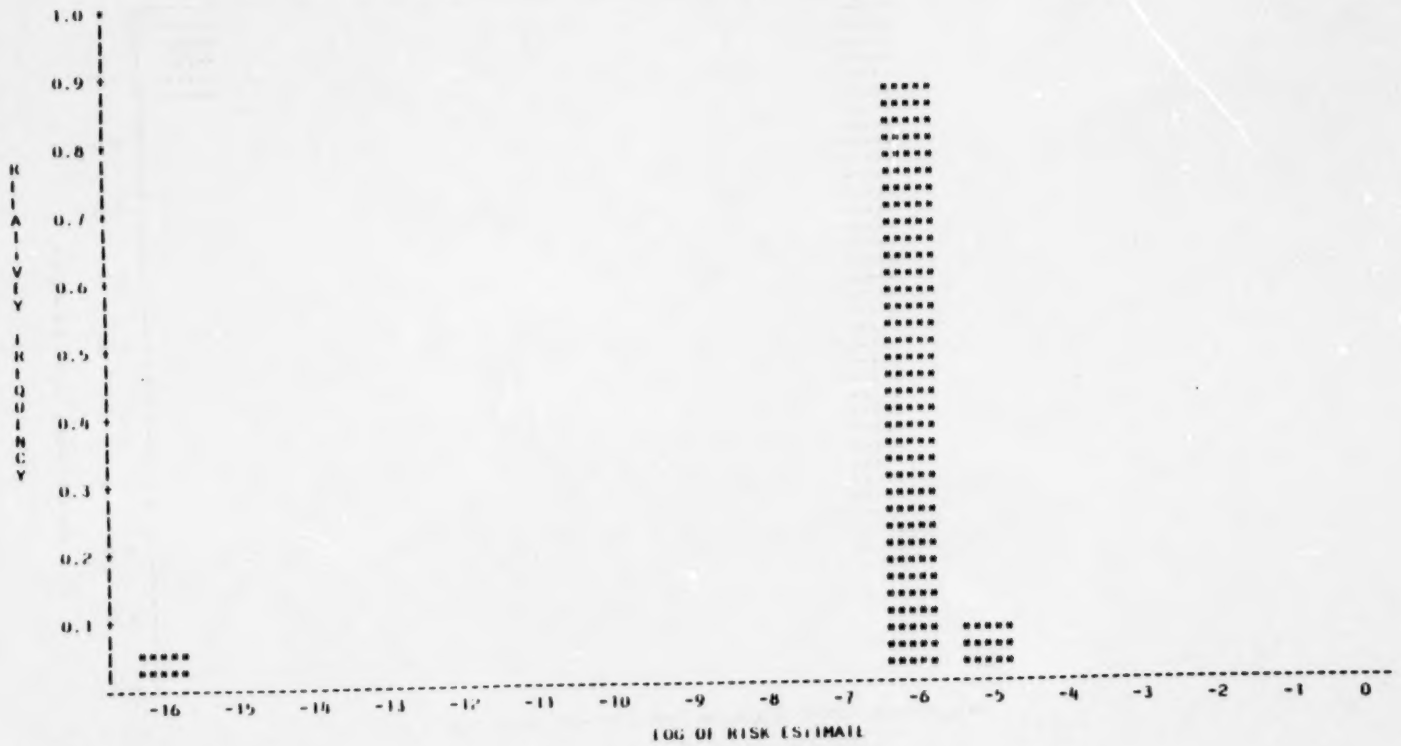
* Frequency distributions based on 6 dominant risk estimates.

EXHIBIT B-28

EXISTING TANK RETROFIT WITH CORROSION PROTECTION AND EXCAVATION ZONE MONITORING

RELATIVE FREQUENCY DISTRIBUTION OF DOMINANT RISK ESTIMATES *
STORAGE TANK, UNDERGROUND, CARBON STEEL, 4,000 GALLONS
WASTE STREAM 0080, GROUND-WATER SCENARIO C
DISTANCE TO WELL 60 M

EXISTING TANK RETROFIT WITH CORROSION PROTECTION AND EXCAVATION ZONE MONITORING



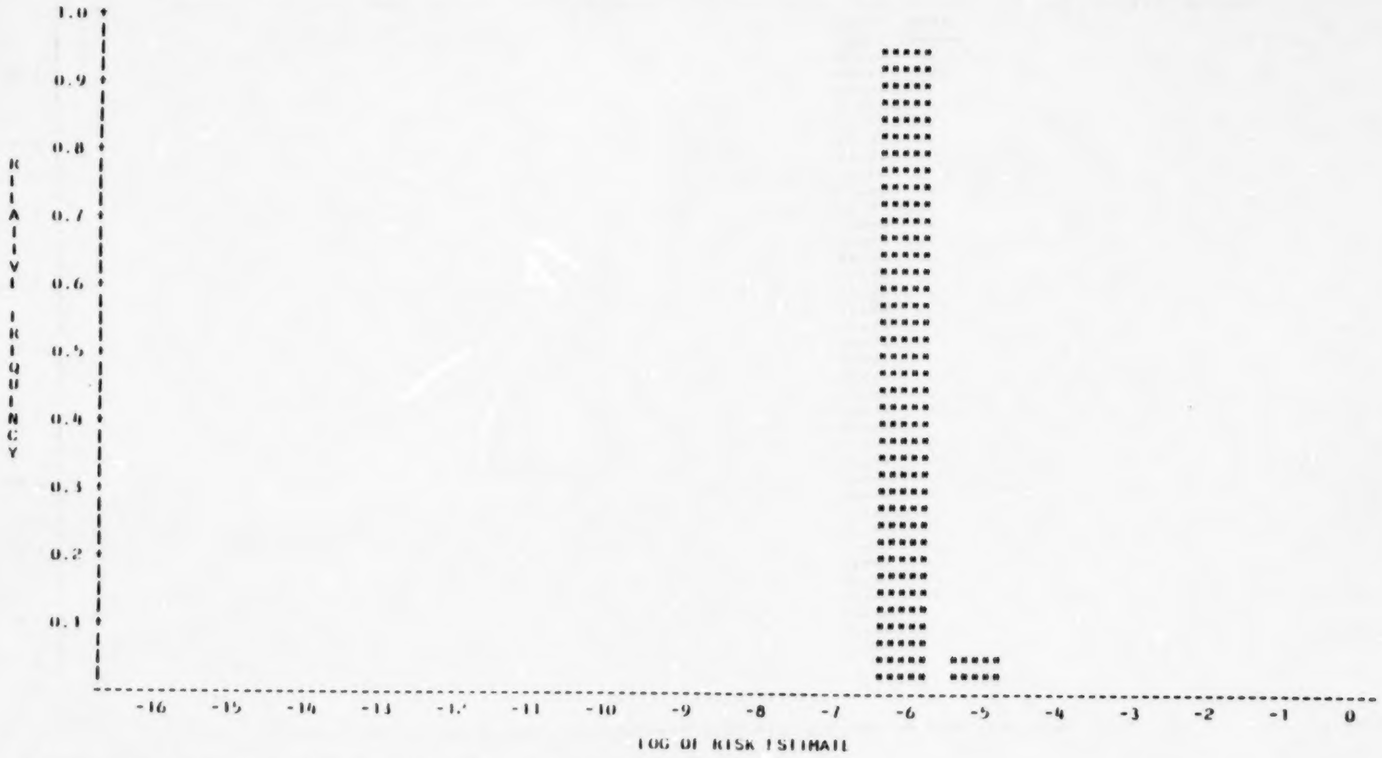
* Frequency distributions based on 6 dominant risk estimates.

EXHIBIT B-29

EXISTING TANK REPLACED WITH TANK EQUIPPED WITH CORROSION PROTECTION AND EXCAVATION ZONE MONITORING

RELATIVE FREQUENCY DISTRIBUTION OF DOMINANT RISK ESTIMATES *
STORAGE TANK, UNDERGROUND, CARBON STEEL, 4,000 GALLONS
WASTE STREAM U080, GROUND-WATER SCENARIO C
DISTANCE TO WELL 60 M

EXISTING TANK REPLACED WITH TANK WITH CORROSION PROTECTION AND EXCAVATION ZONE MONITORING



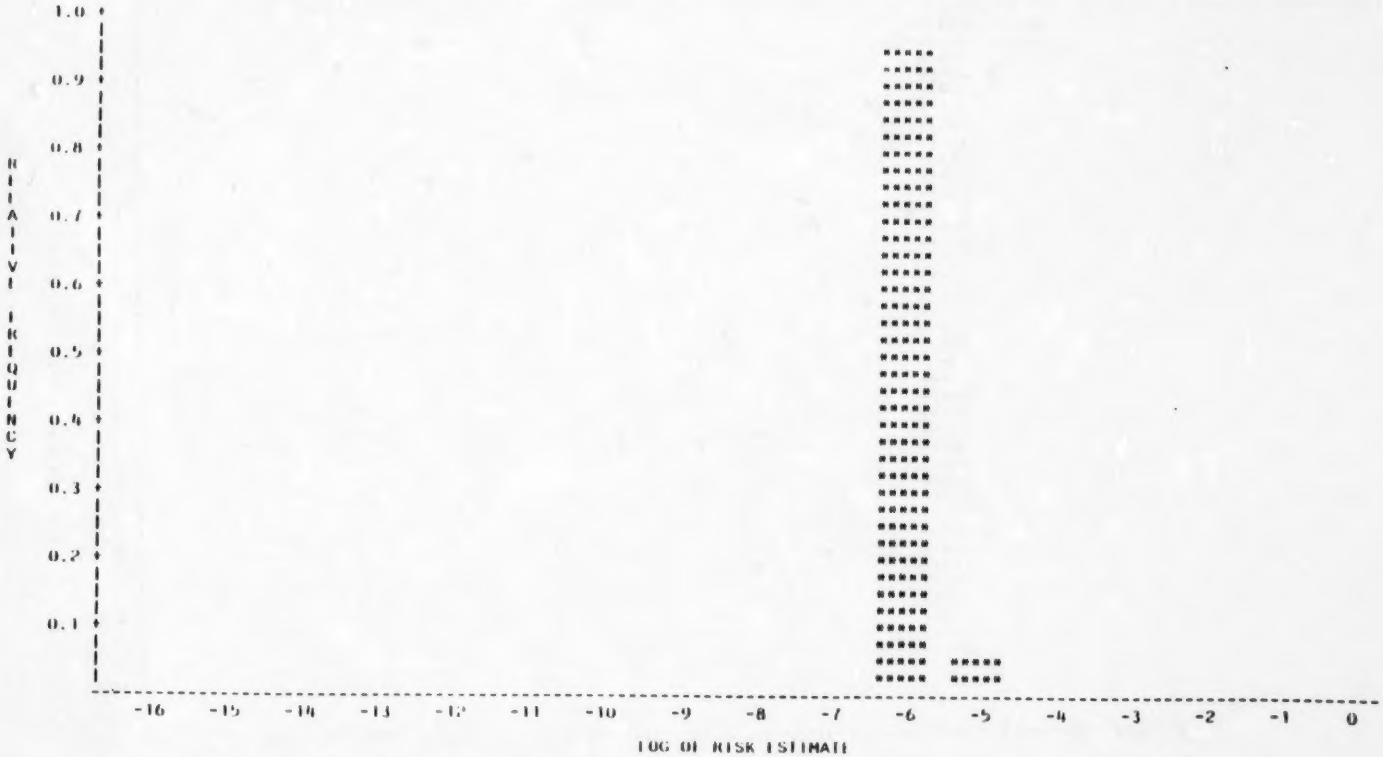
* Frequency distributions based on 6 dominant risk estimates.

EXHIBIT B-30

EXISTING TANK REPLACED WITH NEW TANK EQUIPPED WITH EXCAVATION ZONE MONITORING

RELATIVE FREQUENCY DISTRIBUTION OF DOMINANT RISK ESTIMATES *
STORAGE TANK, UNDERGROUND, CARBON STEEL, 4,000 GALLONS
WASTE STREAM U080, GROUND-WATER SCENARIO C
DISTANCE TO WELL 60 M

EXISTING TANK REPLACED WITH SINGLE-WALLED TANK WITH EXCAVATION ZONE MONITORING



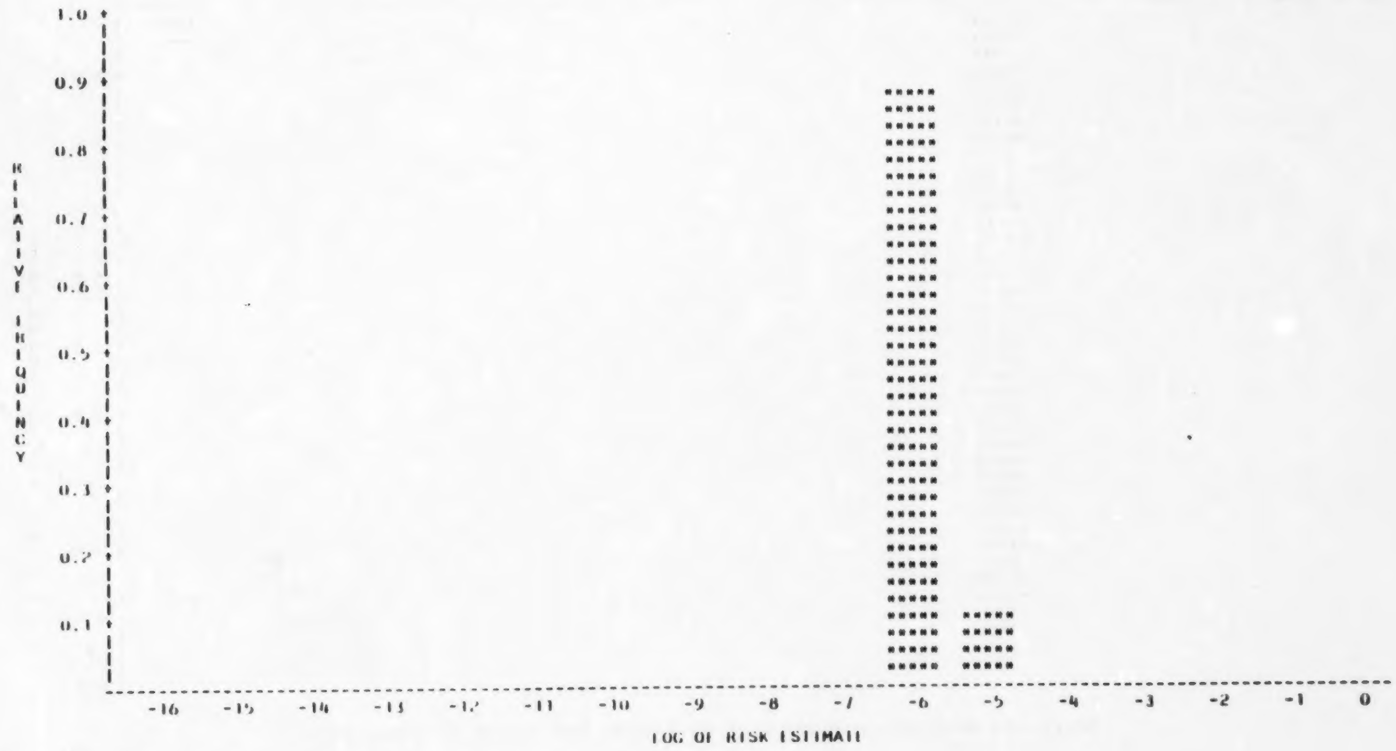
* Frequency distributions based on 6 dominant risk estimates.

EXHIBIT B-31

EXISTING TANK RETROFIT WITH EXCAVATION ZONE MONITORING

RELATIVE FREQUENCY DISTRIBUTION OF DOMINANT RISK ESTIMATES *
STORAGE TANK, UNDERGROUND, CARBON STEEL, 4,000 GALLONS
WASTE STREAM U080, GROUND-WATER SCENARIO C
DISTANCE TO WELL 60 M

EXISTING TANK RETROFIT WITH EXCAVATION ZONE MONITORING



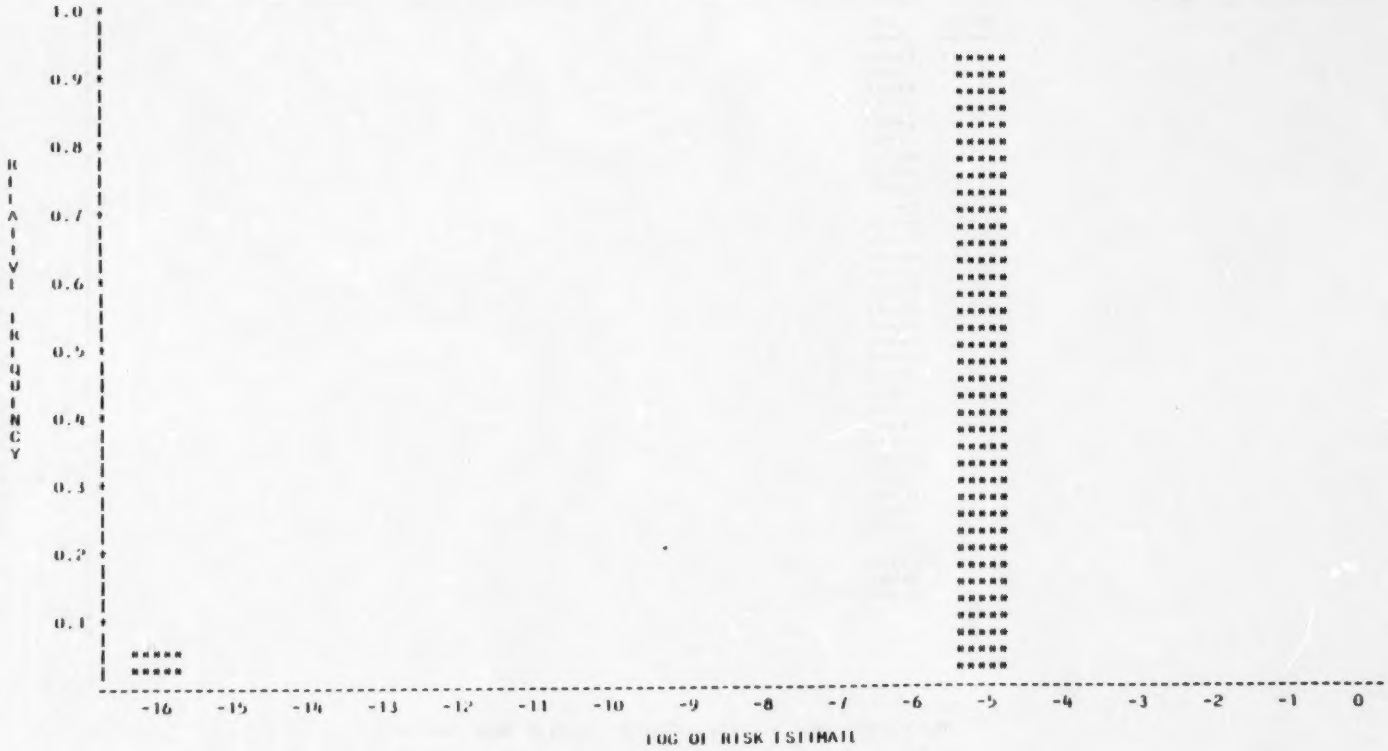
* Frequency distributions based on 6 dominant risk estimates.

EXHIBIT B-32

EXISTING TANK RETROFIT WITH CORROSION PROTECTION AND LEAK TESTED SEMI-ANNUALLY

RELATIVE FREQUENCY DISTRIBUTION OF DOMINANT RISK ESTIMATES *
STORAGE TANK, UNDERGROUND, CARBON STEEL, 4,000 GALLONS
WASTE STREAM U080, GROUND-WATER SCENARIO C
DISTANCE TO WELL 60 M

EXISTING TANK LEAK TESTED SEMIANNUALLY AND RETROFIT WITH CORROSION PROTECTION



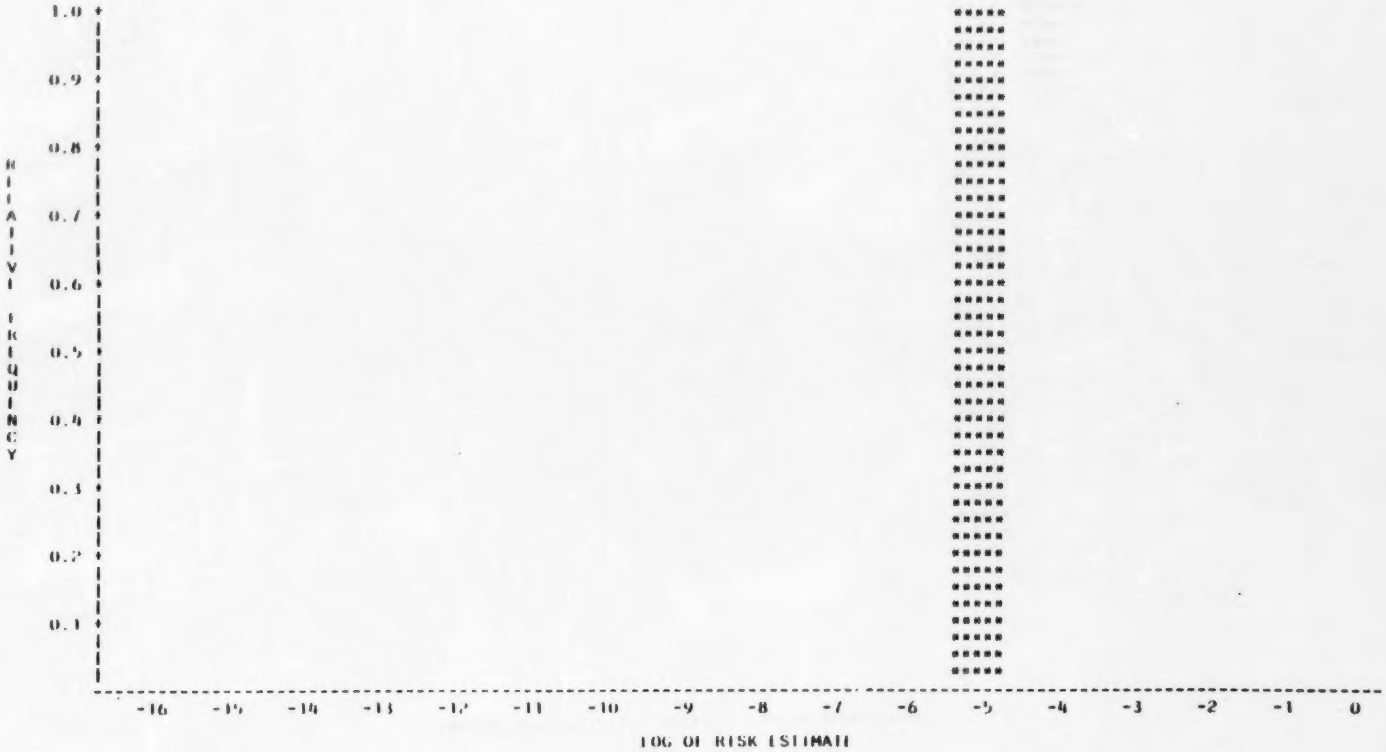
* Frequency distributions based on 6 dominant risk estimates.

EXHIBIT B-33

EXISTING TANK LEAK TESTED SEMI-ANNUALLY

RELATIVE FREQUENCY DISTRIBUTION OF DOMINANT RISK ESTIMATES *
STORAGE TANK, UNDERGROUND, CARBON STEEL, 4,000 GALLONS
WASTE STREAM U080, GROUND-WATER SCENARIO C
DISTANCE TO WELL 60 M

EXISTING TANK LEAK TESTED SEMIANNUALLY



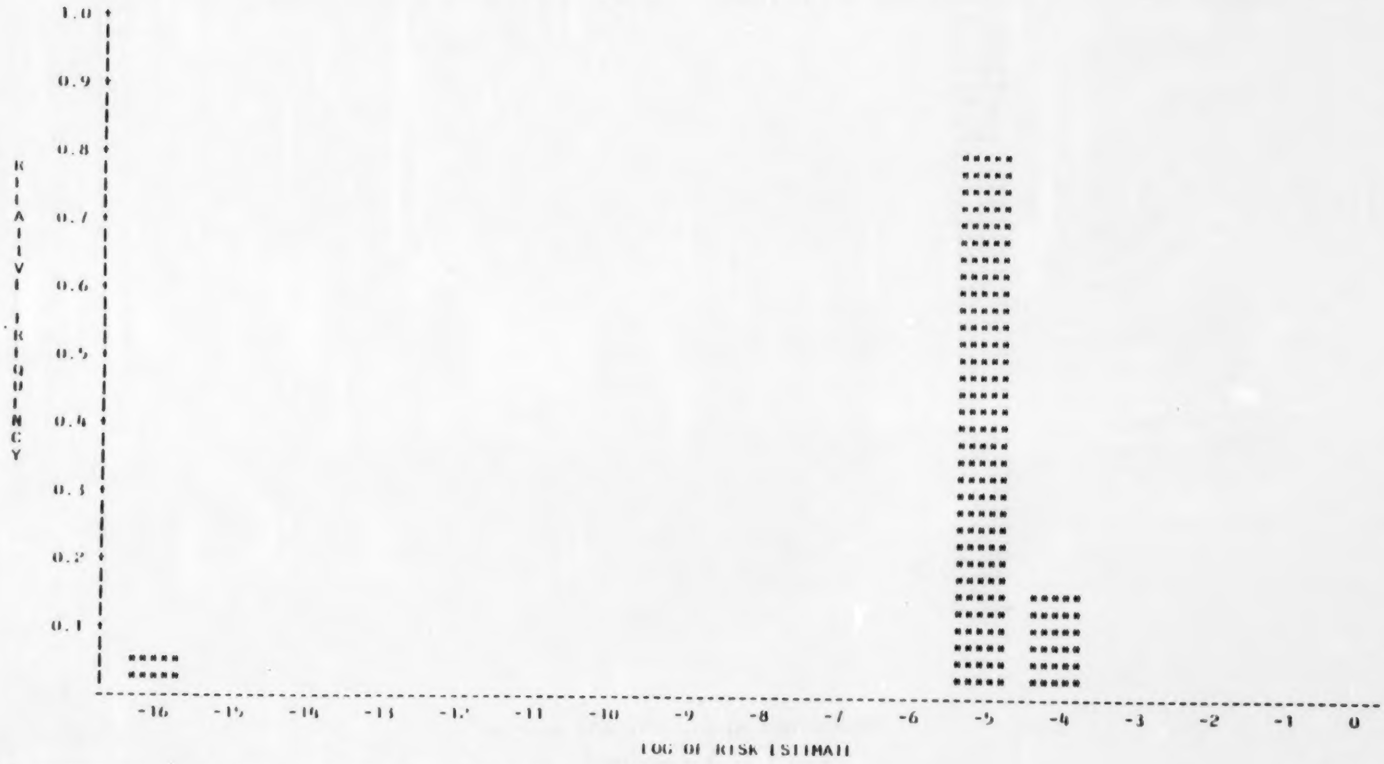
* Frequency distributions based on 6 dominant risk estimates.

EXHIBIT B-34

EXISTING TANK RETROFIT WITH CORROSION PROTECTION

RELATIVE FREQUENCY DISTRIBUTION OF DOMINANT RISK ESTIMATES *
STORAGE TANK, UNDERGROUND, CARBON STEEL, 4,000 GALLONS
WASTE STREAM U080, GROUND-WATER SCENARIO C
DISTANCE TO WELL 60 M

EXISTING TANK RETROFIT WITH CORROSION PROTECTION



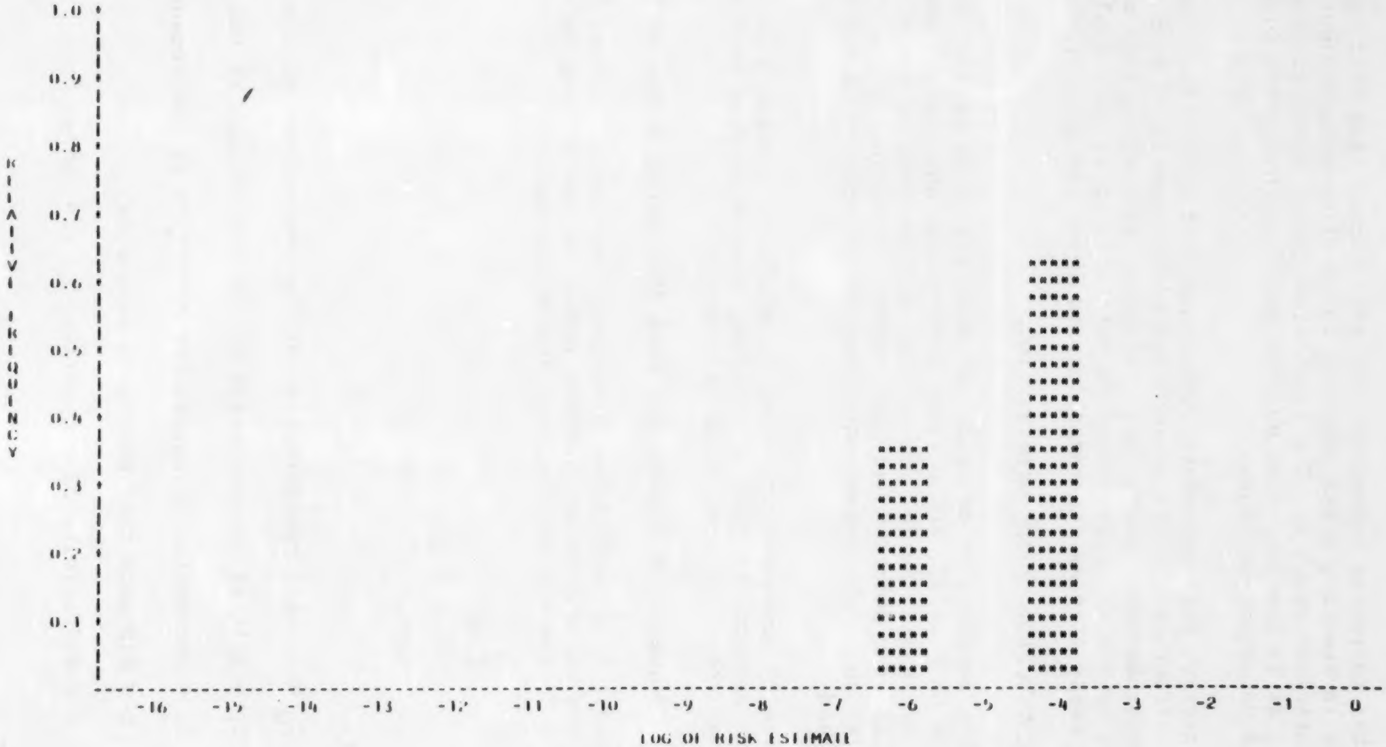
* Frequency distributions based on 6 dominant risk estimates.

EXHIBIT B-35

NEW TANK, BASELINE

RELATIVE FREQUENCY DISTRIBUTION OF DOMINANT RISK ESTIMATES *
STORAGE TANK, UNDERGROUND, CARBON STEEL, 4,000 GALLONS
WASTE STREAM U080, GROUND-WATER SCENARIO C
DISTANCE TO WELL 60 M

EXISTING TANK REPLACED WITH NEW SINGLE-WALLED TANK



* Frequency distributions based on 6 dominant risk estimates.

Neither corrosion protection nor semi-annual leak testing is very effective in reducing risks compared to baseline when employed without any other protection measure. The limitations noted above are partly responsible for this, as is the fact that neither provides both protection against failure and rapid detection of leaks.

In summary, full secondary containment and excavation zone monitoring are the most effective options in reducing risks associated with the model underground hazardous waste tank. Although excavation zone monitoring is an effective option it is important to note that it is only applicable to volatile waste streams and tanks located above the water table.

B.5 EXCAVATION ZONE MONITORING

In this section, we describe our modeling of excavation zone monitoring within the HWTF model, and outline assumptions and limitations affecting the modeling of this scenario. Excavation zone monitoring was not included in the initial analysis described in this report. Moreover, it is the only alternative in which contaminant transport is modeled in the HWTF model rather than in TRAM.

We briefly summarize the model algorithm in Section 5.1. In Section 5.2, we outline assumptions made in modeling excavation zone monitoring, and limitations resulting from these assumptions.

B.5.1 Modeling of Excavation Zone Monitoring in the HWTF Model

Transport of a vapor through stagnant air can be defined by an equation relating the concentration gradient (which is the driving force of mass diffusion) to the distance between source and sensor:[7]

$$\frac{C_0 - C_2}{C_0 - C_1} = \text{erf}\left(\frac{z}{4Dt}\right)$$

where,

C_0 = initial concentration of the contaminant at the source

C_1 = initial concentration of the contaminant at the sensor

C_2 = concentration needed for detection at the sensor

z = distance from source to sensor (m)

D = diffusivity of contaminant in air (m^2/s)

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[7] Louis Thibodeaux, Chemodynamics (New York: John Wiley & Sons, 1979), p. 76. This particular equation is the solution to what is termed semi-infinite solid.

t = time to raise concentration from C_1 to C_2 (s)

erf = standard Gaussian error function

For transport in soils, Thibodeaux has developed a modification to the diffusivity (D) to account for available soil pore space and the tortuous path that the vapor must take as it moves around soil particles:[8]

$$D' = DE/\tau$$

where,

D' = modified diffusivity (m^2/s)

D = diffusivity in air (m^2/s)

E = soil porosity

τ = tortuosity factor (3)

The model uses the modified diffusivity. The initial concentration at the source is assumed to be the vapor pressure of the contaminant expressed as a fraction of the total pressure (0.576 for dichloromethane);[8] i.e., the air space directly surrounding the leak is saturated with dichloromethane vapor. The initial concentration at the sensor is assumed to be zero. The detection threshold concentration at the sensor is 25 ppm.[9] The diffusivity for dichloromethane vapor in air is 1.01×10^{-5} m^2/s.[10]

The transport distance is assumed to be 2 feet (0.61 m) plus the radius of the tank if the leak is originating from a tank, discharge pipe, weld, or gasket. If the source is from a fill pipe, the transport distance is the distance from the mid-point of the pipe to the sensor. In addition, the vapor is assumed to migrate in the direction of the monitoring well. Because the distance between the tank and the well is assumed to be 2 feet and a restricted path (e.g., compacted clay) is assumed to not exist between the tank and the well, only one monitoring well is essentially being modeled.

From the known variables, a time to detection can be calculated. In the model, when a leak develops, the detection time is calculated using the appropriate distance between the source and sensor. Each month, the model will determine if the detection time has been exceeded. If it has, the model will sample a probability value from a binomial distribution to determine if the sensor has failed to detect the contaminant (10 percent chance of failure). If the sensor does not fail, a 1-day response time is added to overall leak time and the failed component is fixed. If the sensor fails, the leak will continue to the next month at which time the sensor will again be checked. If some other monitoring method detects the failure before the vapor well does, the appropriate variables will be reset so as not to interfere with future leaks.

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[8] Ibid, p. 246.

[9] SENSIDYNE, INC. vapor detection literature.

[10] ICF Incorporated, "Modeling of Vadose Zone Monitoring in the Treatment and Storage Tank Failure Model", memorandum to Betsy Tam (EPA) and David Gustafson (PRA), February 3, 1986.

The vapor or transport model is based on the assumption that there is enough liquid at the source to provide for a constant vapor-saturated condition at the source. This assumption has been incorporated as a check at the time the leak has been detected. Assuming that the vapor front is moving out in all directions from the source, the total liquid leak volume converted to a vapor volume should, at a minimum equal the volume occuppied by a sphere of radius equal to the distance to the sensor (adjusted for the porosity, 0.26 for sand taking into account a 0.09 residual saturation); i.e., if the total leak volume evaporated, the vapor will not migrate only in the direction of the sensor, but will migrate in all directions from the leak as a point source. If this check is not satisfied at the estimated detection time (as calculated by the transport equation), the leak will continue until this volume is attained.

B.5.2 General Assumptions Used to Model Excavation Zone Monitoring

Excavation zone monitoring is the only technical alternative for tank management included in this analysis that was not considered in the initial analysis. It is also the only situation in our analysis in which contaminant transport is predicted within the HWTF model rather than in TRAM. Thus, given the short time frame over which the excavation zone model algorithm was developed and the fact that it has not been extensively reviewed, we believe it is particularly important to state explicitly the assumptions and limitations inherent to this scenario. These include:

- Excavation zones for hazardous waste tanks are composed of homogeneous, isotropic sand of known permeability. In reality, most tank excavations for existing tanks are backfilled with the material originally contained in the excavation, which in most cases would not be homogeneous or isotropic. Thus, the assumption that tank excavations are backfilled with homogeneous, isotropic sand is non-conservative for existing tanks in that it probably under-estimates vapor-phase contaminant transport times from a leak point to a vapor well and consequently under-estimates risk for existing tanks. For new tanks, the assumption is more reasonable because tank operators desiring to use excavation zone monitoring may be required to fill the excavation zone with homogeneous material such as sand or gravel.

- Monitoring well is located two feet from the tank, within the excavation zone. Given that many tank operators do not know the exact location of their underground tanks,and that excavation areas may vary from location to location for the same size tank, it is unlikely that an excavation zone monitoring well (vapor well) could be placed so accurately at existing tank sites. For new tanks, wells could be placed at the time of tank installation and could be located more accurately.

- Tanks equipped with an excavation zone monitoring well are located in areas where the water table is low enough to allow for significant volatilization to take place before a leak reaches the saturated zone. For modeling excavation zone monitoring this is a necessary assumption; in reality, however, some portion of the existing population of hazardous waste tanks is located in high or variable water table areas where excavation zone monitoring would be impractical. Our analysis is not applicable to tanks located in these types of settings.

- Hazardous waste tanks utilizing excavation zone monitoring for leak detection always store the same volatile waste at approximately the same concentration. Data indicate that many hazardous waste tanks store a variety of waste mixtures with highly variable composition, making excavation zone monitoring an unreliable alternative for leak detection. However, in order to test this scenario in our analysis it was necessary to make the assumption that the characteristics of the waste stored within the tank were constant over the entire 20-year modeling period.

These assumptions illustrate that excavation zone monitoring is a complex scenario to model, and also that it is more limited in its application to the population of hazardous waste tanks than options such as secondary containment, leak testing, and corrosion protection.